ASBESTOS AS A HAZARDOUS CONTAMINANT II

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Ministry
of the
Environment

The Honourable
William G. Newman,
Minister

Everett Biggs,
Deputy Minister

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AIR RESOURCES BRANCH

Special Studies and Programm Planning Group
Technology Development & Appraisal Section

Report No. ARB-TDA-01-75

ASBESTOS AS A HAZARDOUS CONTAMINANT II

Ministry of the Environment
Air Resources Branch
880 Bay Street, 4th Floor
Toronto, Ontario

January 1975

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SUMMARY ABSTRACT

Asbestos is such an ubiquitous mineral in the economy of Ontario that, when concern arose about the serious health effects associated with the mineral, it was necessary to evaluate the potential problems posed by the production and use of asbestos and asbestos containing materials within the province. This report investigates the general properties of asbestos silicates, the sources and control of asbestos emissions, measurement techniques and asbestos-induced health effects, all in relation to the ambient atmosphere of Ontario. Recommendations as to the air quality standard development, overall program design, and the role of the Air Resources Branch of the Ontario Ministry of the Environment have been presented.

01. SUMMARY

The naturally occurring fibrous silicates classified as "asbestos" have become almost indispensable in modern technology. The objectives of this report are to:

a) determine how this mineral enters Ontario's atmospheric environment;
b) obtain knowledge of the measuring techniques for asbestos and an indication of the concentrations to expect;
c) try and determine the detrimental effects of the mineral and their severities;
d) finally, recommend a program of action.

In Ontario, there are presently two producing and proposed chrysotile asbestos mines, however, 1974 production was behind that of Quebec, Yukon, Newfoundland and British Columbia. There is extensive industrial asbestos process and product diversification in Ontario using approximately 95% - 99% chrysotile fibre with small amounts of imported amosite and crocidolite. The total quantity of crude fibre consumed by the Ontario asbestos industry is approximately 34,000 tons, 59% of which is used by a single asbestos-cement manufacturer. The majority of the operations (numbering over 20) involve the production of asbestos-containing construction materials.

Although there is no universal standardized method for ambient air sampling of asbestos, the methodology outlined in this report is generally consistant with that presented by several other agencies and laboratories. There is a general concensus that when dealing with ambient air, analysis procedures require electron microscopy. From previous surveys, it was found that asbestos concentrations in ambient urban air will

range from .5 ng/m^3 - 15 ng/m^3.

The major reason for the necessity of a standard is the effect of asbestos on the health of humans. Chapter 08. entitled "Health Effects" was written by the Ontario Ministry of Health.

The control techniques for asbestos are outlined in this report. The principle of "best available technology", in most instances, specifies the use of fabric filters (baghouse) but, there are many sources that are too mobile, dispersed or infrequent to warrant conventional methods of control. In these cases, a code of practice must be promulgated as an emission abatement reinforcement.

Although there are several agencies proposing ambient air quality standards for asbestos, the Environmental Protection Agency in the United States is the only authority at the moment who has an official standard. Ontario has established an interim guideline for asbestos of 5 ug/m^3.

Finally, an ambient air sampling program has been designed for asbestos to fulfill two major goals:

1) to acquire an indication of present asbestos concentrations in ambient air in Ontario;
2) to acquire knowledge of the character (ie., size distribution, etc.) of the samples of asbestos from various sites/sources.

This survey will require one year to complete starting in February, 1975, and the total cost will be approximately $50,000.

02. RECOMMENDATIONS

02.01 AIR QUALITY CRITERIA

1. It is recommended that a point of impingement standard as well as an ambient air quality objective be set to control asbestos emissions into the atmosphere.

2. It is recognized that control of asbestos emissions at the source is essential if the standards and objectives are to be realized. It is recommended that this control be effected by the following two strategies:

    a) a point of impingement (30 min. legally enforceable) standard set tightly enough to require "best available technology" control procedures as recognized by the asbestos operations in all cases.

    b) the creation of an extensive code of practice covering all aspects of the use of asbestos.

3. It is recommended that the concentration unit used be fibre per cubic metre (f/m^3).

4. It is recommended that a comprehensive code of practice be written for asbestos sources that cannot be controlled by conventional control equipment (ie., fabric filters). This code, to cover all of the varied sources of asbestos emissions into the atmosphere, should be based on the best available practical control technology for the particular operation.

02.02 MEASUREMENT METHODS AND AIR SAMPLING PROGRAMS

02.02.01 AIR SAMPLING PROGRAMS

1. It is recommended that an ambient air sampling campaign be initiated for the Province of Ontario. The program will have two goals, which are:

   a) to acquire an indication of ambient asbestos concentrations near and removed from various sources in Ontario.

   b) to acquire knowledge of the character (eg., size distributions, etc.) of the sampled asbestos from various locations.

   Since insufficient data exist on ambient concentrations of asbestos in Ontario, it is very important to get an accurate assessment of these levels. Further, it is recommended that the Technology Development & Appraisal Section of the Ontario Ministry of the Environment, carry out this sampling and analysis program and that the samples be taken for a six month period beginning in February and analyzed concurrently. The importance of both summer and winter measurements is realized. The program is outlined in more detail in Chapter 10.

2. Conditional to the results obtained from the air sampling program outlined in 02.02.01, #1, it is recommended that a source testing program be conducted by the Technology Development & Appraisal Section of the Ministry of the Environment to obtain the design information needed for the assessment of control. Two of the important types of measurements would be:

   a) the testing of many sources to enable the calculation of a 30-minute point of impingement standard. This would include inlet/outlet sampling.

b) the determination of the particle size distribution characteristics of various sources and the variance between sources. Testing must be downstream of the control equipment.

02.02.02 SAMPLING AND ANALYZING TECHNIQUES

1. It is recommended that the sampling technique to be at least used in the initial sampling program will utilize 47 mm. nucleopore membrane filters with a pore size of .4 um sampling at 40 L/min. for approximately 4-8 hours, depending on the expected concentration of the air.

2. It is recommended that the analysis of the initial sampling program be carried out entirely by transmission electron microscopic techniques, possible including selected area diffraction, Energy Dispersive X-Ray, and electron microprobe analysis. It is further recommended that, since the character of the ambient air samples is very important to this initial sampling campaign, sample manipulation be held to a strict minimum. The analysis should include:

   - the number of fibres per cubic meter
   - an estimate of the mass
   - size categories (length and width)
   - fibre size distribution
   - cumulative size distribution
   - cumulative mass distribution

3. It is recommended that, based on the results of the initial sampling program, the Regions with the Ontario Ministry of the Environment carry on the environmental monitoring, especially of asbestos emission

sources using the recommended sampling techniques.

4. It is recommended that the Technology Development & Appraisal Section of the Ministry of the Environment investigate other longer term sampling techniques (eg., 30 days) that have sufficient precision with the operational practicality and financial consideration kept in mind. Other quicker, less expensive, analytical methods should be investigated also (eg., optical or scanning electron microscopy) since the detail required in the initial sampling program is not needed here.

02.03 CONTROL OF ASBESTOS EMISSIONS

1. It is recommended that the Regions of the Ministry of the Environment survey all plants and determine what measures should be taken to meet best available technology and proposed standards.

2. It is recommended that the control technology to be applied to specific industrial groupings be investigated by the New Technology Unit of the Technology Development & Appraisal Section. The information gained would be input for the assessment of conventional control equipment for asbestos sources (ie., what the "baghouse" will do on various sources). This work would be supported by the stack sampling of selected asbestos sources acquired for design information.

02.04 ABATEMENT OF EMISSIONS TO MEET STANDARDS AND OBJECTIVES

1. It is recommended that, during the Region's initial survey as described in 02.03 #1, blatantly uncontrolled emissions should be rectified immediately without awaiting the standard.

TIME FRAME CHART

PERFORMING SECTION (Within Ontario Ministry of the Environment)	RESPONSIBILITY	COMPLETION DATE
Criteria, Development and Program Planning Group, Air Resources Branch.	Set air quality guidelines. Set air quality criteria & standards.	January, 1975 January, 1976
Monitoring and Instrument Development Section, Technology Development and Appraisal Group (TDA), Air Resources Branch.	Ambient air sampling survey.	February, 1975
Source Monitoring Section, Technology Development and Appraisal Group, Air Resources Branch. (To be performed under contract.)	Stack testing surveys.	December, 1975
Northwestern Region Northeastern Region Southeastern Region Central Region West Central Region Southwestern Region Air Resources Branch	Regional inspection of all asbestos operations.	July, 1975
Special Studies and Preventive Planning Section, Technology Development and Appraisal Group, Air Resources Branch.	Research future ambient air monitoring methods.	December, 1975

03. INTRODUCTION

Asbestos has become a toxic contaminant of increasing concern. This report will investigate the important aspects of this mineral including its effect on health, measurement techniques and sources and control of emissions into the atmosphere. The objectives of the report are:

(1) to discuss the detrimental aspects of asbestos

(2) to determine how and where this mineral enters the atmosphere

(3) to recommend a program of abatement (which will include an air quality standard) that would minimize the negative effects.

03.01 HISTORICAL PERSPECTIVE

Asbestos is a general name for a variety of useful fibrous minerals with thousands of technologically modern applications. But not only is it a valuable commodity today, it is rich in tradition and history. The use of asbestos wss first recorded in 450 B.C. when Herodotus described enshrouding corpses with asbestos cloth before cremation to permit easy collection of the ashes for burial.(12) The Greeks, who used asbestos for the wicks of their temple lamps, were enthralled when flames did not consume it, but burned unceasingly. Amazed, they called it "asbesta" which meant "the unquenchable" or "the inextinguishable".(1)(2)(3) Charles V used the unusual properties of asbestos to amaze and amuse court visitors by throwing table cloths in the fire, from which they usually emerged whiter than when they went in.(3) Charlemagne, used the aura of superstition and mystery attached to the mineral to impress visiting court dignitaries.(12)

In classical times, asbestos, best known for its fire resistance, was woven into cloth to preserve the ashes of persons of noble rank(4) and today this property is appreciated by the wearer of fire-fighting dress. It was used 4,500 years ago (2,500 B.C.) to strengthen clay pottery(5) and today, most of the short-fibred material strengthens asbestos-cement products.

Asbestos, as much as it has been an important element in an historical perspective, is an integral part of the economic life of today's society. The modern industry dates from the 1870's when serious development was stimulated by demonstrations of novel asbestos products and the discovery of large deposits in the province of Quebec and near Sverdlovsk in Russia.(4)

The value of asbestos ensues from the indestructable nature of products fabricated from the various grades of mineral fibres. The major asbestos minerals fall into two main categories. The first, chrysotile (white asbestos), is mined from serpentine rock found mainly in Canada, the U.S.S.R., Rhodesia, South Africa and Cyprus. The second group, mined from sedimentary ironstone, is the amphibole series, comprised of three main varieties: amosite (amber), crocidolite (blue), and anthophyllite (white) with tremolite and actinolite being of very minor importance. Amosite is mined mainly in Transvaal (South Africa). Anthophyllite is mined mainly in Finland and is of less commercial interest. Crysotile accounts for 90% of the world production of asbestos ore,(4) and greater than 95% of the asbestos used in industry(7) with amosite and crocidolite being of lesser importance. World production of the mineral has increased sixty times since the turn of the century and five times between 1945 and 1965, the present total being four million tons.(4)(6) The United States uses just under one-fourth of the world production(8) or nearly 800,000 tons,(7) practically all of it imported from Canada and South Africa.

03.02 THE CANADIAN PERSPECTIVE

The first Canadian deposit of chrysotile was discovered in the region of the Des Plantes River near the villages of St. Joseph and St. Francis in the province of Quebec. Between 1862 and 1877, deposits at Thetford, Quebec, were being mined on a commercial basis and, at about the same time, a large deposit was uncovered at Asbestos, Quebec. More recently, the Black Lake deposit in Quebec has been developed. In British Columbia, the Cassiar deposit, producing good quality chrysotile, came into production in 1954-1955. Since 1963 in Newfoundland (at Baie Verte), the Advocate Mines have produced a fibre good for the production of asbestos-cement products. Finally, two Ontario mines are currently in operation in the Lake Abitibi and Matheson areas of northeastern Ontario; Hedman Mines in Warden Township and Johns-Manville Mining and Trading in Reeves Township. Table 1. summarizes the basic data on all producing chrysotile mines in Canada.

In Canada, 90,532,000 tons of asbestos rock were mined in 1970(10) with the production of asbestos fibre totalling 1,654,000 tons.(9) Canadian mining figures dropped to 79,180,000 tons by 1972(10) but, more recently and although mining and milling operations are still not working at full capacity, mineral production has steadied itself as new areas are being opened up. Provincial statistics, which are presented in Table 2., indicated that the companies operating in Quebec, which have employed some 28,000 workers,(11) accounted for 82% of Canada's production(9) and almost half of the world's supply of chrysotile.(11)

The majority of Canadian asbestos is exported as fibre after milling. In 1970, approximately 94.5% of production or 1,562,000 tons of fibre were exported to over 80 countries where the principal customers (United States, Britain, Japan, West Germany) paid $227 million for this

TABLE 1.(9)(10)

ASBESTOS MINING OPERATIONS IN CANADA

NAME	HEAD OFFICE OR GENERAL OFFICE	LOCATION	MINE DESCRIPTION	MILL CAPACITY (tons ore/day)
Newfoundland				
Advocate Mines Ltd................	7 King St. East, Toronto........	Baie Verte	Open Pit	6,000
Quebec				
Asbestos Corporation Ltd..........	Canada Cement Bldg., Montreal...	Thetford Mines, Black Lake. Coleraine, Ugava.	All open pit with the exception of 2 underground operations at Thetford.	Black Lake 11,200 600 600
Bell Asbestos Mines Ltd...........	Box 99, Thetford Mines..........	Thetford Township		Thetford
Lake Asbestos of Quebec Ltd.......	Box 88, Black Lake..............	Black Lake		8,000
National Asbestos Ltd.............	Box 459, Thetford Mines.........	Thetford		3,000 2,000
Canadian Johns-Manville Co. Ltd...	Box 1500, Asbestos..............	Asbestos.............	....	32,000
Carey Canadian Mines Ltd..........	Box 190, East Broughton Station.	East Broughton Sta...	....	4,000
Ontario				
Hedman Mines Ltd..................	Box 590, Timmins................	Warden Township	Open Pit	300
Johns-Manville Mining & Trading Ltd.	106 B Third Ave., Box 2003,..... Timmins, Ontario.	Reeves Township	Open Pit	5,000
British Columbia				
Cassiar Asbestos Corp. Ltd........	85 Richmond St. W., Toronto.....	Cassiar	Open Pit	2,400
Yukon				
Cassiar Asbestos Corp. Ltd........	85 Richmond St. W., Toronto.....	Clinton Creek	Open Pit	3,000

TABLE 2.[9]

CANADIAN ASBESTOS FIBRE PRODUCTION IN 1970

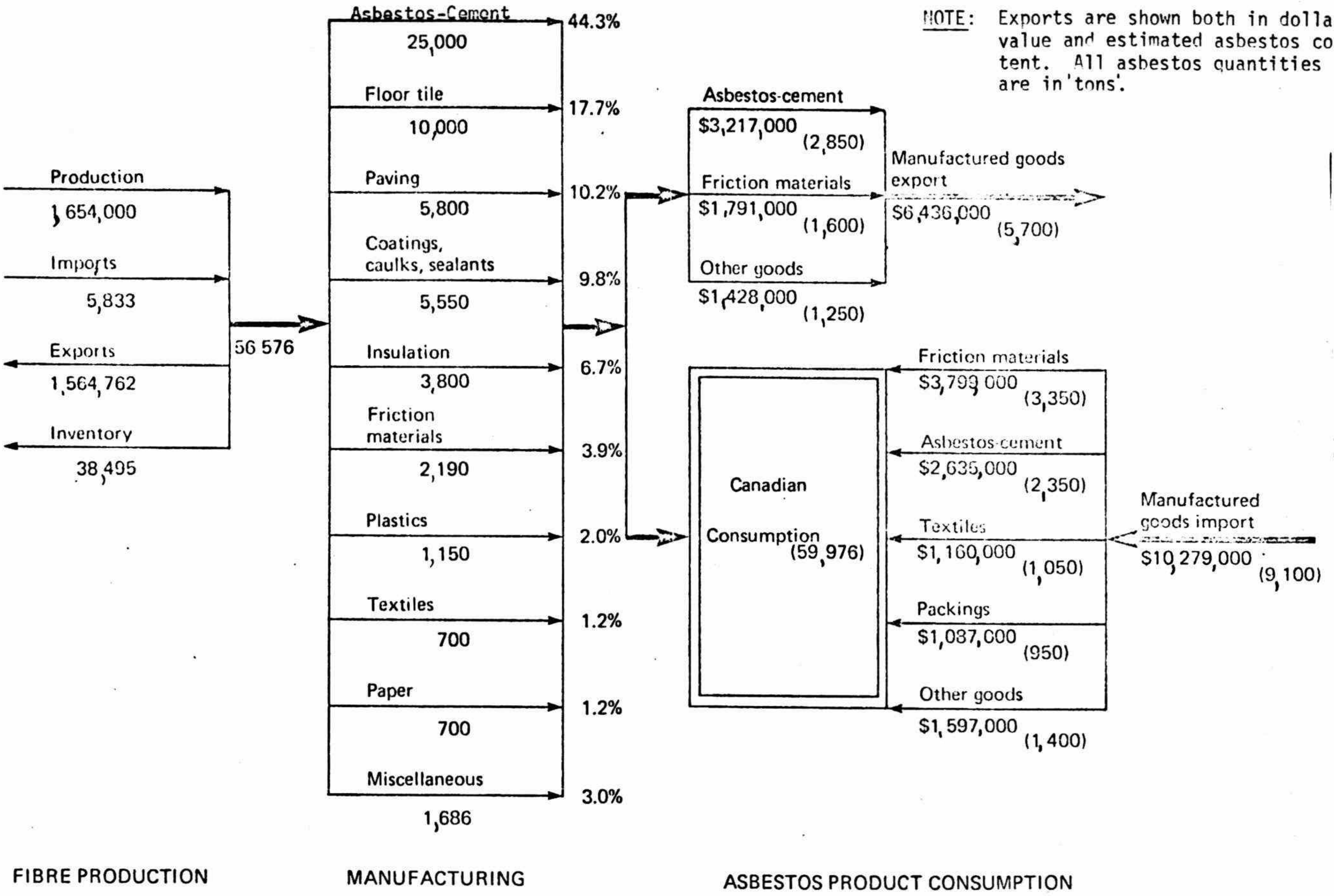
PROVINCE	QUANTITY (1000 Tons)	PERCENT
Quebec	1,353	81.8
Yukon	108	6.5
British Columbia	89	5.4
Newfoundland	66	4.0
Ontario	38	2.3
TOTAL	1,654	100.0

raw material ($145/ton on the average).(9) The remaining 5.5% fraction was split between consumption by Canadian industry, which required 50,743 tons or 3% of domestic production, and inventory stockpiles by asbestos producers, which absorbed 38,495 tons or 2.5% of production.(9) Canadian industry also consumed 4,784 tons of amosite asbestos imported from South Africa, 909 tons from Venezuela, and 140 tons from Britain, the bulk of the 5,833 tons of imported fibre used in the manufacture of pipe insulation.(13)

In a study by James F. MacLaren Ltd. for Environment Canada, the consumption of asbestos in Canada (1970) was estimated, shown in Figure 1. Approximately 62% of the total Canadian usage was accounted for by two industries. The manufacturers of asbestos-cement products required 25,000 tons (44.3% of consumption), and the manufacturers of floor tile required 10,000 tons (17.7% of consumption). Ten percent of the total tonnage used by Canadian industry was exported as manufactured goods, whereas 90% was sold domestically.

03.03 ECONOMIC OUTLOOK

The economic forecast for asbestos producers in Canada looks bright. Despite a substantial increase in production during the past year, the strong demand for asbestos has reduced inventories to a point where some producers may have to put their customers on an allocation basis.(15) Although the Ontario Mineral Review indicates a slump in production between 1969-1972,(17) the Canadian industry set a production record in 1973, up 20% from 1972.(15)(17) Asbestos shortages still developed late in the year. These shortages could last for three or four years if the growth in consumption continues at its present rate of about 4.5% annually.(15) Consequently, the tight demand/supply situation in asbestos has resulted in unprecedented price increases.



NOTE: Exports are shown both in dollar value and estimated asbestos content. All asbestos quantities are in tons.

Figure 1. CANADIAN ASBESTOS FLOW IN 1970 (SHORT TONS)

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04. PHYSICAL AND CHEMICAL PROPERTIES OF ASBESTOS

04.01. INTRODUCTION

Asbestos is a general term referring to a variety of mineral types, all with unique and valuable properties. The properties that make asbestos most useful are both chemical and physical in nature.

A. Chemical Properties

   a) inflammability
   b) low thermal conductivity
   c) resistance to oxidation
   d) resistance to corrosive chemical substances and micro-organisms
   d) high electrical resistance

B. Physical Properties

   a) fine fibre size
   b) high wear strength

There are six varieties of asbestos belonging to either the serpentine or amphibole series. The serpentine group, which consists solely of the chrysotile variety of fibre, is used in about 90% of all products requiring asbestos.(7) The amphibole series consists of anthophyllite, amosite, and crocidolite are the most commercially useful. Amphibole fibres are generally large in cross-section, appear as straight narrow sheets and are solid whereas chrysotiles are exceedingly small in cross-section and are tubular. In general, the amphiboles are harsh, hard, springy, and not as flexible and soft as chrysotile. Various properties of the different varieties are discussed below and Table I is a compilation of the more important ones.

04.02. GEOLOGY AND ORIGIN

The geological ages involved in the formation of asbestos are the post-ordovician and pre-devonian followed by the middle and upper devonian.(7) In Canada, the chrysotile asbestos originates from such rocks as dunite, peridotite, and pryroxenite which have been altered to serpentine by hydrothermal reactions acting upon magnesia-rich minerals such as olivine, forsterite, enstatite and diopside.(7) Crocidolites and amosites occur in metamorphosed siliceous-ferruginous sediments rich in iron and silica called banded ironstones.

It has been suggested that chrysotile developed through the action of solutions which originated from outside the serpentine belt.(7) The replacement of the serpentine or peridotite by chrysotile took place through selective solutions and crystallization in the solid rock, and the fibre veins developed from openings in the rock. It has also been suggested that maybe the magnesia and a portion of the silica of the vein-forming materials were obtained from the wall rock. It is further suggested that perhaps several stages of crystallization took place along with the heating of the wall rock and that stress conditions were set up to convert the picrolite into asbestos.(7)

04.03 SERPENTINE (CHRYSOTILE) ASBESTOS

Chrysotile is structurally similar to the clay material kaolinite.(15) It has a sheet structure consisting of alternating layers of an octahedrally coordinated Mg-O-OH layer and a tetrahedrally coordinated Si-O layer. (15) The composition of chrysotile can be represented as $Mg_6(OH)_8\ Si_4O_{10}$ with the following chemical breakdown: SiO_2 = 37-44%; MgO = 39.44%; FeO = 0.0 - 6.0%; Fe_2O_3 = 0.1-5.0%; Al_2O_3 = 0.2-1.5%;

TABLE 1. PROPERTIES OF ASBESTOS FIBRES (7)

	CHRYSOTILE	ANTHOPHYLLITE	AMOSITE (ferroanthophyllite)	CROCIDOLITE	TREMOLITE	ACTINOLITE
structure	in veins of serpentine, etc.	lamellar, fibrous asbestiform	lamellar, coarse to fine fibrous and asbestiform	fibrous iron-stones	long, prismatic and fibrous aggregates	reticulated long prismatic crystals and fibers
mineral association	in altered peridotite adjacent to serpentine and limestone near contact with basic igneous rocks	in chrystalline schists and gneisses	in crystalline schists, etc.	in iron-rich silicious argillite in quartzose schists	in Mg limestones as alteration product of highly magnesian rocks, metamorphic and igneous rocks	in limestone and in crystalline schists
origin	alteration and metamorphism of basic igneous rocks rich in magnesian silicates	metamorphic, usually from olivine	metamorphic	regional metamorphism	metamorphic	results of contact metamorphism
veining	cross and slip fibers	slip, mass fiber unoriented and interlacing	cross fiber	cross fiber	slip or mass fiber	slip or mass fiber
essential composition	hydrous silicates of magnesia	Mg silicate with iron	silicate of Fe and Mg, higher iron than anthophyllite	silicate of Na and Fe with some water	Ca and Mg silicate with some water	Ca, Mg, Fe, silicates, water up to 5%
Crystal structure	fibrous and asbestiform	prismatic, lamellar to fibrous	prismatic, lamellar to fibrous	fibrous	long and thin columnar to fibrous	long and thin columnar to fibrous
crystal system	monoclinic (pseudo-orthorhombic?)	orthorhombic	monoclinic	monoclinic	monoclinic	monoclinic
color	white, gray, green, yellowish	grayish, white, brown, gray or green	ash gray, greenish or brown	lavender, blue, greenish	gray-white, greenish, yellowish, bluish	greenish
luster	silky	vitreous to pearly	vitreous, somewhat pearly	silky to dull	silky	silky
hardness, Mohs	2.5 - 4.0	5.5 - 6.0	5.5 - 6.0	4	5.5	6±
specific gravity	2.4 - 2.6	2.85 - 3.1	3.1 - 3.25	3.2 - 3.3	2.9 - 3.2	3.0 - 3.2
cleavage	010 perfect	110 perfect	110 perfect	110 perfect	110 perfect	110 perfect
optical properties	biaxial positive extinction parallel	biaxial positive extinction parallel	biaxial positive extinction parallel	biaxial extincition inclined	biaxial negative extinction inclined	biaxial negative extinction inclined
refractive index	1.50 - 1.55	1.61±	1.64±	1.7 pleochroic	1.61	1.63 weakly pleochroic
fusibility, Seger cones	fusible at 6, 1190 - 1230°C	infusible or difficulty fusible	fusible at 6, loses water at moderate temperatures	fusible at 3, 1145 - 1170°C	fusible at 4, 1165 - 1190°C	fusible at 4, 1165 - 1190°C
flexibility	very flexible	very brittle, nonflexible	good, less than chrysotile	fair to good	generally brittle, sometimes flexible	brittle and nonflexible
length	short to long	short	2" to 11" varies	short to long	short to long	short to long
texture	soft to harsh, also silky	harsh	coarse, but somewhat pliable	soft to harsh	generally harsh, sometimes soft	harsh
acid resistance	soluble up to approximately 57%	fairly resistant to acids	fairly resistant to acids	fairly resistant to acids	fairly resistant to acids	relatively insoluble in HCl
spinnability	best	poor	fair	fair	generally poor, some are spinnable	poor
specific heat, Btu/(lb)(°F)	0.266	0.210	0.217	0.201	0.212	0.217

H_2O = 12.0-15.0%; CaO = 0.0-5.0%.(7) Recent accurate determination of density show it to be 2.53-2.58.(7)

Chemically, a 0.5% suspension of chrysotile in water free of carbon dioxide acts somewhat like magnesium hydroxide, having a pH of 10.33.(7) Magnesium hydroxide suspended in distilled water in the same manner has a pH of 10.37. However, aqueous suspensions of chrysotile have a higher electrical conductivity than saturated solutions of magnesium hydroxide, indicating the presence in solution of other soluble electrolytes. Acids will readily attack chrysotile and dissolve the magnesium, leaving mostly a silica structure.

The tensile strengths of chrysotile fibres have been reported as varying from 100,000 psi. to 400,000 psi.(7) The Young modulus is approximately 23.1 X 10^6 lb/in^2.

Chrysotile fibres and fibrils are distinctive in their appearance and their morphology is usually utilized for their identification by electron microscopy. Chrysotile fibres are usually curved and they readily divide into numerous flexible fibrils (a chrysotile fibre of 1 um. diameter can yield 1,000 fibrils of the same length.(15) Consequently, no reliable geometric size measurements can be made with chrysotile fibres. However, the average outer diameter of a chrysotile fibril will range from 200-250 Å and an inner diameter of 20-100 Å.(7)(15)

Electron microscope pictures of chrysotile seem to indicate the existence of hollow tubes with an apparently amorphous material on the outside and inside of the tubes. Other forms are occasionally observed, for example, a tube-in-tube and cone-in-cone form.(15) These tubes are not simply cylindrical cones, but consists of spirally wound layers. Some fibres, however, are not hollow but solid, showing an unusual growth problem. The density of Arizona and African chrysotile is compatible with the tubular structure, but Canadian Chrysotile, with a high density, has at least 50% filled tubes.

04.03.01 STRUCTURAL CHANGES DUE TO HEAT

The nonflammability of asbestos results from structural changes that occur under the action of heat. For chrysotile, absorbed water is driven off at about 324.9°C and the water of crystallization is lost between 581.4°C and 632.7°C.(4) As dehydration takes place, the fibres start to deteriorate. Deterioration begins at approximately 427.5°C.(4)(7) The fibres are completely destroyed, and the fibrous chrysotile changes into the nonfibrous mineral fosterite (Mg_2SiO_4) above 581.4°C. Amphibole asbestos behaves similarly, but will withstand slightly higher temperatures without deterioration.(4)

04.04. AMPHIBOLE ASBESTOS

Amphiboles are derived from the Greek work meaning ambiguous and without careful work they can be easily misidentified. In particular, electron diffraction and X-ray diffraction patterns are similar for different varieties and their compositions are overlapping. The amphiboles consist of "double chains" of linear silica tetrahedra with cautious linking the chains together.(15) For each variety of amphibole, there is a corresponding massive form, often with a different mineral name.

The name cummingtonite is used to describe monoclinic amphibole containing 30% to 70% $Fe_7\ Si_8\ O_{22}$ and grunerite for the more iron-rich members. The characteristic feature of the cummingtonite-grunerite mineral is the fibrous and a characteristic multiple twinning.(15)

Amosite is an acronym for fibrous commercial grade cummingtonite from South Africa (Asbestos Mines of South Africa). Previous to 1960, amosite was mistakenly called anthophyllite since the optical extinction angle is almost 0^o as would be the case with an orthorhombic mineral.

Tremolite and actinolite are essentially metamorphic minerals and occur in both contact and regionally metamorphosed rocks. Actinolite and ferro-actinolite are commonly associated with cummingtonite in metamorphosed iron formations.

Crocidolite is the fibrous variety of fourth reaction at 900-1,000°C due to oxidation of FeO with the collapse of the structure and riebeckite rock. In a thin section or hand specimen, it is easily recognized by its pleochroism - blue irridescence and angle of extinction. It has a similar electron diffraction pattern to the other monoclinic amphiboles but can easily be recognized by its composition.

The chemical composition of amphiboles is more complex than that of chrysotile. The amphibole structure admits great flexibility of ionic replacement, and the minerals of the group exhibit a wide range of chemical composition. In addition to the replacement (Mg, Fe), important substitutions occur in the amphiboles, for example, the substitution of silicon by aluminum, calcium by sodium, etc.

04.04.01 AMOSITE

Amosite asbestos can be regarded as a high iron (or low magnesium) anthophyllite. The empirical formula is expressed as $Fe_5 Mg_2 Si_8 O_{22} (OH)_2$.(7) Chemical analyses show:

SiO_2 = 49.53%
Al_2O_3 = 2-9%
MgO = 1-7%
H_2O = 2-5%
FeO = 34-44%
CaO and Na_2O = 0.5-2.5%

Differential thermal analysis (DTA) shows an exothermic reaction at 300-400°C and 650-735°C due to magnetite impurities and the third and fourth reaction at 900-1,000°C due to oxidation of FeO with the collapse of the structure and liberation of water.(7) Apparently, no endothermic reaction takes place.

The fibres are harsh, fairly brittle and are comparatively large in size as seen by the electron microscope. The molecules apparently form straight flat sheets. This fibre has good heat and acid resistance. Tensile strengths vary from 16,000 to 170,000 psi. with Young modulus of 23.6×10^6 lb/in.^{2}.(7)

04.04.02 ANTHOPHYLLITE

Anthophyllite asbestos is a magnesium iron silica $(MgFe)_7Si_8O_{22}(OH)_2$, but low in iron. A pure magnesium anthophyllite $Mg_7Si_8O_{22}(OH)_2$ upon disintegration produces enstatite ($MgSiO_3$), cristobalite (SiO_{22}) and water. If iron is present, magnetite (Fe_3O_4) is also produced. Analyses of anthophyllites show:(7)

SiO_2 = 56-58%
Al_2O_3 = 0.5-1.5%
MgO = 28-34%
H_2O = 1-6%
FeO = 3-12%

Differential thermal analysis data on anthophyllite shows an exothermic reaction around 830°C due to oxidation of FeO and an endothermic reaction around 1,015°C with the liberation of water and no structure change.(7)

Electron micrographs show anthophyllite fibrils to be in large flat sheets. The fibres vary from soft to semi-harsh to brittle in texture. They have good heat resistance, acid resistance and a low tensile strength less than 4,000 psi.

04.04.03 CROCIDOLITE

Crocidolite asbestos is a sodium iron silicate. An accepted empirical formula is $Na_2O.Fe_2O_3.3FeO.8SiO_2.H_2O$. It is found mainly in Africa and Australia with smaller deposits in Bolivia and Labrador.(7) The approximate chemical analyses are as follows:

SiO_2 = 49-53%
MgO = 0-3%
FeO = 13-20%
Fe_2O_3 = 17-20%
H_2O = 2.5-4.5%
Na_2O = 4.0-8.5%

Crocidolite, upon disintegration, forms acmite ($Na_2O.Fe_2O_3.4SiO_2$), hematite (Fe_2O_3), cristobalite and water.(7)

Two small exothermic reactions occur between 348-405°C followed by an intense endothermic reaction between 940 and 1,027°C. The exothermic reaction forms acmite.

The structure of crocidolite resembles the flat sheets of amosite rather than the tubular appearance of chrysotile. However, electron micrographs show crocidolite to be straight needles and apparently thinner in cross-section than amosite. Crocidolite fibres are not so easily attacked by acids as amosites, although small amounts can be leached out.

The heat resistance of this fibre is fair to poor, but its acid resistance is good. Tensile strengths can vary from 100,000 psi. to over 500,000 psi.(7)

04.04.04 TREMOLITE-ACTINOLITE SERIES

These two fibres differ chemically in the amount of iron present in the molecule. The tremolite formula is $Ca_2Mg_5Si_8O_{22}(OH)_2$. Tremolite disintegrates into diopside-clinoenstatite ($CaSiO_3.MgSiO_3$), cristobalite and water. Actinolite disintegrates into a complex series of diopside-clinoenstatite-hedenbergite ($CaSiO_3.MgSiO_3.FeSiO_3$), cristobalite and water.

An exothermic reaction occurs on tremotite around 820°C and an endothermic reaction around 900 to 1,040°C.(7) DTA data on actinolite show a small exothermic reaction at 355°C and an endothermic reaction at 1,122°C.

Electron micrographs for tremolite show large thick structures whereas actinolite is smaller in width but very brittle and shows signs of shattering when preparing the sample for the picture. Tremolite, in many cases, shows good fibrous structure and it is quite useful in commercial products where, on the other hand, actinolite is used only as a cheap filler. Tensile strength values vary from 1,000 to 8,000 psi and the texture varies from flexible to harsh and brittle.

04.05 SURFACE AREA OF ASBESTOS

The specific areas of the asbestos fibres are important for the study of kinetics of dissolution of asbestos fibres in water. Surface areas can be measured by using nitrogen adsorption and permeability methods.

The values obtained by the nitrogen adsorption method includes all the internal surface of pores, cracks, etc., while the permeability method measures only the external surface. Surface measurements of chrysotile can vary depending upon the degree of fibrization of the fibre. Nitrogen adsorption techniques have shown surface areas varying from 4 to 12 m^2/g and by additional fibrization, these values can be increased to 30 or even 50 m^2/g.(15) This is a very high value, greater than for any of the usual natural or man-made textile fibres.

04.06 COLOUR OF ASBESTOS

The varities of asbestos are found and even named by their characteristic colour. The colour is related to its chemical composition, chrysotile being "white" asbestos, amosite being "brown" asbestos and crocidolite being "blue". The composition is that of a silicate with chain-type silica lattice to which various metals may be bonded.(9) In the case of chrysotile, it is magnesium; of amosite it is iron and magnesium; and of crocidolite, it is sodium and iron.

04.07 REACTION OF ASBESTOS FIBRES IN WATER AND BIOLOGICAL FLUIDS

Chrysotile will break down chemically and physically in a variety of environments, especially when separated in their unit fibrils.(13) Chrysotile has been shown to chemically degrade in distilled water into a magnesium compound, and soluble silica acid.(13)(15) It is postulated that the dissolution of the chrysotile accompanied by the solution of the magnesium leaves a residue of collidal silica that hydrolyzed to orthosilicic acid.

Chrysotile is chemically unstable in a biological environment. Physically, the fibres, composed of bundles of fibrils, tend to break open

TABLE 2.(10)

Comparison of Chromium, Cobalt and Nickel Concentrations
of UICC Reference Samples Between Morgan *et al* and
(Cralley *et al*)

FIBRE AND SOURCE	CHROMIUM (ppm)	COBALT (ppm)	NICKEL (ppm)
African Chrysotile	600-1700 (1390)	< 100 (55)	1200-2900 (1250)
Canadian Chrysotile	100-1200 (490)	<100-100 (46)	100-2000 (990)
African Amosite	< 100 (35)	< 100 (7)	< 100 (< 100)
African Crocidolite	< 100 (16)	< 100 (2)	< 100 (< 100

while in biological residence. There also appears to be a "thinning" of the fibril walls suggesting a loss of material "in vivo".(13) Magnesium has also been shown to leach from fibres while in the lungs of rats.(13) On the other hand, amphibole fibres tend not to split or change shape in lung fluids and are thus observed in the same state as when inhaled.

04.08 TRACE METALS IN ASBESTOS

Trace metal analysis of asbestos is of increasing importance as same researchers have attributed asbestos-induced diseases to the carcinogenic potential of some of the trace metals found with the asbestos. Cralley et al revealed appreciable concentrations of chromium, cobalt, nickel and manganese(6) as did Keenan and Lynch.(14) Groth reported beryllium, cadmium, copper, thallium and postulated the damaging effect on the lung.(14) Now there are eight trace metals known with distinct concentration ranges.

Lockwood's investigations showed:(14)

Beryllium:	2-14 ug*	Copper:	9-26 ug
Cadmium:	3-10 ug	Manganese:	325-1065 ug
Chromium:	202-771 ug	Nickel:	299-1187 ug
Cobalt:	30-78 ug		

* micrograms of metal per gram of asbestos.

Data obtained by Cralley et al(6) agrees well with results obtained by Holmes et al and with values more recently obtained by Morgan and Sandals,(10) as can be seen from Table 2. Generally it was found that chrysotile had greater amounts of nickel and chronium, whereas amosite was higher in manganese.(6) Crocidolite had the lowest trace metal content.(6) The iron content of Canadian chrysotile is 1.9 - 4.8% with up to half associated with a magnetite impurity.(10)

Trace metal constituents of asbestos are not always structurally incorporated in the fibre and may be present in association with contaminating minerals such as magnetite, brucite, or chromite.(10)

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05. SOURCES AND CONTROL OF EMISSIONS INTO THE ATMOSPHERE

05.01 INTRODUCTION

This section will discuss in depth the sources of asbestos emissions into the ambient air and the control of these. Expected source strengths will be presented and the degree and feasibility of control analyzed. The principles of in-plant control techniques will be discussed briefly.

05.02 USES OF ASBESTOS

From early Greek times, when asbestos cloth was worn by slaves and the dead were preserved in this cloth when buried,(52) asbestos has proven through the years to be one of the most useful and versatile minerals available. Today, it is used in more than 3,000 products.(1)(5) Since it is impervious to heat and is fibrous, asbestos is the only mineral that can be woven into cloth so, consequently, it is spun into fireproof clothing and theatre curtains as well as household items like non-combustible drapes, rugs, pot holders and ironing board covers. Floor tiles, roofing felts, plasterboards and wall boards are also made with asbestos. Asbestos is an ingredient of plaster, stucco and many paints and putties. It is probably present in some form or another in every home, school, office building and factory in the country. Since it is also used in brake linings, clutch facings, mufflers, gaskets, sealants, caulking and extensively used in ships, asbestos is a component of every modern vehicle, including space ships. Since the material is economic in cost, use and maintenance and is highly resistant to corrosion, either through exposure to weather or buried in the ground,(3) it is widely used in the cement and insulation industries. Table 1 lists the uses of asbestos in more detail.

TABLE 1.

Asbestos Friction Materials -

- Brake Linings
  - Woven, containing asbestos yarn, tape, or cloth
  - Molded, including all nonwoven types
- Clutch Facing
  - Woven, containing asbestos yarn, tape, or cloth
  - Nonwoven - Clutch lining
    - Transmission lining

Asbestos-Cement Materials -

- Flat sheets and wallboard, all thicknesses converted to 1/4" basis
- Slabs
- Corrugated sheets
- Pipes
- Corrugated tiles for roofs in industry, agriculture, and dwellings
- Planks for platforms in buildings under construction
- Balcony canopies
- Rain gutters
- Interior walls
- Ventilating shafts
- Air conditioning assemblies
- Pressure piping (for underground drinking water distribution systems, fuel gas, and sewage)
- Cooling towers (electricity-generating stations)
- Asbestos felts
  - Roofing-asphalt or tar saturated
  - Other
- Other asbestos and asbestos-cement products, including millboard and prefabricated housing components

Asbestos Shingles and Clapboard

- Siding shingles and clapboard, including accessories
- Roofing shingles

Asbestos Textiles -

- Asbestos textiles
  - Yarn, cord, and thread
  - Cloth
  - Other asbestos textiles, including roving, lap, wick, rope, tape, carded fibers, etc.

Gaskets and Insulation -

- Gaskets, All Types
- Gaskets (for sealing nonmoving parts)
  - Asbestos, asbestos-metallic, and asbestos-rubber

TABLE 1. (Cont'd)

Packing (except leather, rubber, and metal) and asbestos insulations
- Asbestos compressed sheet

Packing (for sealing moving parts)
- Asbestos, asbestos-metallic, and asbestos-rubber

Insulation materials containing asbestos pipe insulation
- Cellular and laminated
- 85 percent magnesia
- Diatomaceous silica, calcium, silicate, expanded silica, and asbestos fiber
- Other pipe insulation

Block insulation, including sheet and lagging
- 85 percent magnesia
- Diatomaceous silica, calcium silicate, expanded silica, and asbestos fiber
- Other block insulation, including cellular and laminated
- All other asbestos insulation

Asbestos Boards and Papers -

Boards
- Filtering and clarifying
- Coverings, coatings, casings, and jacketings for all kinds of surfaces
- Manufacturing of welders' and melters' shields
- Slideways in the glass industry
- Handles and fire-doors
- Auto Parts
- Safes
- Protective walls
- Curtains, etc.

Sheets
- Inner/outer linings of furnaces and heating vessels, drying ovens, incubators, heaters, climate-controlled spaces, etc.

Plates
- Insulating buildings against vibrations (aluminum-asbestos)
- Solar-heat reflecting surfaces (70% of solar heat)

Special Asbestos Papers
- Filters

Asbestos Plastics -

Flooring tiles (asbestos-asphalt tiles and, increasingly, asbestos-polymers of vinyl)

Pressed or molded (thermal insulation and in electrical machinery)

Resinated asbestos felt (manufacturing of wings and firing of missiles and expansion cones for nozzles of boost motors). Other uses in aircraft industry: nozzles for motor tubes, missile tailpipes, and missile-heat barriers; fuselages for guided missiles, fuel tanks for fighter bombers, cabin floors, etc.

TABLE 1. (Cont'd)

Asbestos Acid-Resistant Compositions -

Used mostly in chemical industry

Sources: (1) (5) (17) (37) (14)

05.03 EMISSION SOURCES (GENERAL)

Many products, at times unknown to the user, contain asbestos of one kind or another. There are chances of fibre release during the use of the product. The likelihood of release depends predominantly on the ease with which the fibres can be dislodged by the application of energy and on the degree to which the application of energy actually destroys the fibres during the use of the product.(2) Most asbestos fibres become tightly bound within the product and usually undergo little actual wear or abrasion and are therefore not considered a problem (ie., cement products, vinly asbestos tile, etc.) except when these materials are reshaped or uncoated, fibres become free and are released through the friction, destruction or deterioration.(7) In some products, the asbestos is not tightly bound or mixed with another material and fibre release occurs during the application and removal of the product so special precautions must be taken for control purposes (ie., asbestos textiles, insulation materials).(2)(7) Some asbestos products, such as brake linings, are subject to a great deal of friction and, therefore, must be considered a possible emission source.

The sources and subsequent control of emissions can be divided into five categories:

(1) natural sources of airborne fibres
(2) mining and milling of asbestos
(3) manufacture of products containing asbestos
(4) the consumption of asbestos products
(5) disposal of asbestos waste materials

05.04 NATURAL SOURCES OF AIRBORNE FIBRES

Approximately 30 varieties of asbestos are widely distributed in rocks occurring at, or near, the surface of the earth.(2)(15) Natural erosion processes, which are estimated to weather approximately 10^{10} tons of rock annually on a world wide basis,(15) will accordingly release asbestos fibres into the air, water and soil. Asbestos fibres can become airborne during roadbuilding, construction, tilling of the soil, and landslides, besides erosion and weathering.

It would be desirable to have information on the background levels of asbestos because this would assist in evaluating the effects of control measures and permit some estimates of the lower limits of contamination that might be achieved in different areas of the country. At present, no figures are available on background levels.

05.05 MINING AND MILLING OF ASBESTOS

05.05.01 MINING

Chrysotile, which is the fibrous form of serpentine, and crocidolite, amosite, anthophyllite, tremolite, and actinolite which are fibrous forms of the amphibole minerals, usually occur in veins embedded in massive rock deposits. The three fibre types are cross, slip or bulk. The concentration of asbestos in commercial ores ranges from as much as 60% in short fibre ore to 3%-10%(15) in longer fibre deposits. Information concerning Halliday and Midlothian Townships in Ontario and the proposed United Asbestos Mine at Lloyd Lake indicates that stringers and veinlets of cross- and slip-fibre asbestos cut the serpentinized ultra-nafic intrusive rocks in a zone 4,000 ft. by 200 ft. along the north shore of Lake Lloyd.(69) Approximately 9%-10% of the ore is chrysotile.(16)(71)

When deposits of asbestos occur near the surface of the earth and are not bound within massive rock deposits, surface mining methods are employed. The shallow overburden and the ore are removed by power shovel and bulldozer or by other scraper-type methods. The mining proceeds along either parallel or spiral terraces, which extend to the floor of the pit. In addition, open-pit and underground mining are sometimes applied concurrently, as in the Quebec mines.

Table 2 lists the history of chrysotile asbestos production in Ontario. At present, there are three asbestos mines operating or proposed for Ontario by 1975, all open-pit.(15)

(1) Hedmand Mines Limited is currently mining approximately 150 tons of asbestos ore per day in Warden Township and milling this material at their mill in Matheson(46) (capacity 300 tons/day(15)).

(2) Canadian Johns Manville is reopening their asbestos mine and mill at Reeve Township west of Timmins. Expected milling rate is 5,000 tons/day.(46)
(Feb.20/75, this mine closed down for an indefinite period.

(3) United Asbestos is currently constructing a new mine and mill in Midlothian Township near Matachewan. Expected milling rate is 3,500 tons/day.(16)

A typical asbestos operation is shown schematically in Figure 1. Holes are drilled into the deposit with compressed air or electric drills, and blasting then loosens the ore. Rough separation of ore and barren rock in the pit is followed by power shovel loading of trucks and transportation of ore to the mill.

EMISSIONS

Each of the processes associated with asbestos mining is a potential source of emission. Local meteorological conditions can significantl aggravate mining and milling emissions. For example, rain, sleet and snow

TABLE 2

CHRYSOTILE ASBESTOS PRODUCTION IN ONTARIO*

Year	Tons	Value	Mine	Operator
1917	10	$ 2,150	Slade-Forbes	Slade-Forbes Asbestos Company
1923	6	2,600	Bowman	Bowman Asbestos Mines
1924	172	91,900	Bowman	Porcupine Asbestos Mining Syndicate
1925	2	901	Bowman	Porcupine Asbestos Mining Syndicate
1926	14	3,935	Bowman	Porcupine Asbestos Mining Syndicate
1937	1	250	Rahn Lake	Rahn Lake Mines Corporation Limited
1939	18	720	Rahn Lake	Rahn Lake Mines Corporation Limited
1950	10,518	1,493,099	Munro	Canadian Johns-Manville Company Ltd.
1951	26,549	3,766,769	Munro	Canadian Johns-Manville Company Ltd.
1951	38	6,300	Slade-Forbes	Teegana Mines Limited
1952	23,033	3,847,853	Munro	Canadian Johns-Manville Company Ltd
1952	63	14,800	Slade-Forbes	Van Packer Mines of Canada Ltd.
1953	23,529	3,965,299	Munro	Canadian Johns-Manville Company Ltd.
1954	21,389	3,497,824	Munro	Canadian Johns-Manville Company Ltd.
1955	24,550	3,317,542	Munro	Canadian Johns-Manville Company Ltd.
1956	26,748	3,929,782	Munro	Canadian Johns-Manville Company Ltd.
1957	20,947	3,529,570	Munro	Canadian Johns-Manville Company Ltd.
1958	21,650	3,849,370	Munro	Canadian Johns-Manville Company Ltd.
1959	24,350	4,327,628	Munro	Canadian Johns-Manville Company Ltd.
1960	23,284	4,128,920	Munro	Canadian Johns-Manville Company Ltd.
1961	25,047	4,362,668	Munro	Canadian Johns-Manville Company Ltd.
1962	35,551	5,686,720	Munro	Canadian Johns-Manville Company Ltd.
			Hedman	Hedman Mines Limited
1963	33,715	5,372,645	Munro	Canadian Johns-Manville Company Ltd.
			Hedman	Hedman Mines Limited
1964	15,512	2,199,918	Munro	Canadian Johns-Manville Company Ltd.
			Hedman	Hedman Mines Limited
			Reeves	Johns-Manville Mining & Trading Ltd.
1965	1,758	69,258	Hedman	Hedman Mines Limited
1966	1,696	64,519	Hedman	Hedman Mines Limited
1967	1,631	61,240	Hedman	Hedman Mines Limited
1968	17,554	2,107,014	Hedman	Hedman Mines Limited
			Reeves	Johns-Manville Mining &Trading Ltd.
1969	36,068	4,375,475	Hedman	Hedman Mines Limited
			Reeves	Johns-Manville Mining & Trading Ltd.
1970**	38,000	4,961,000	Hedman	Hedman Mines Limited
			Reeves	Johns-Manville Mining & Trading Ltd.

*Production 1917-1952 reproduced from Hewitt and Satterly (1953, p.4); Statistical Files, ODMNA

**Preliminary figures.

Source: (70)

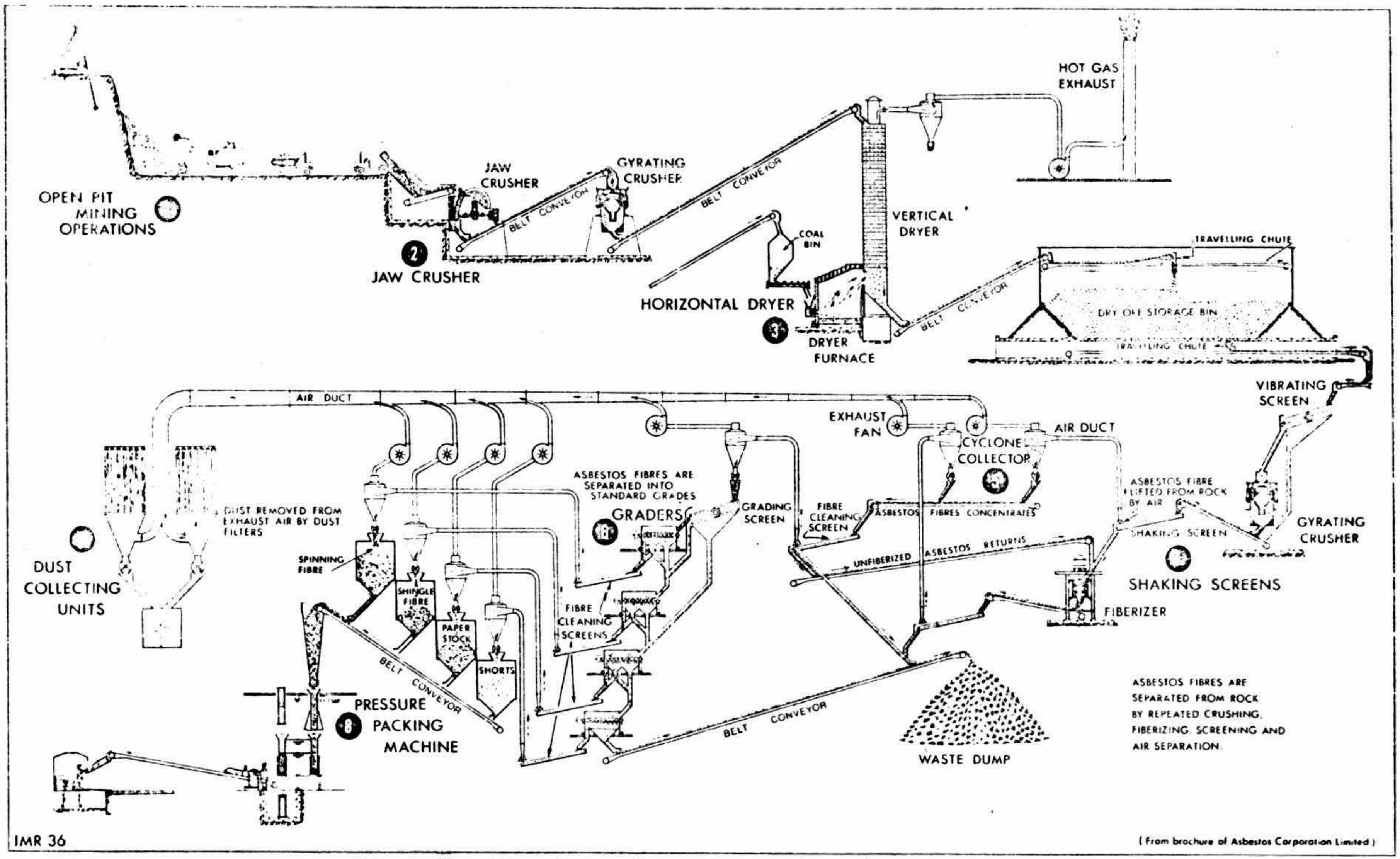


Figure 1 - Flowsheet of an asbestos operation

Source: (70)

tend to reduce emissions because they result in wetting or covering exposed ore deposits in addition to scavenging the atmosphere but, conversely, strong winds are capable of widely dispersing existing emissions as well as eroding waste rock dumps, tailings and any other loosely bound asbestos fibres in material exposed to the atmosphere by mining operations.

In those surface mining operations that require blasting, the use of rotary or percussion drilling machines that incorporate air-flushing is a potential source of appreciable amounts of dust emissions.(14) Air-flushing refers to the use of an air stream, operated by pressure, vacuum, or pressure and vacuum in combination, to cool the drill bit and lift cuttings out of the hole formed for placement of explosive charges. Air travels down the hollow center of the drill bit as the drill cuttings move upward along the outside of the bit. Smaller dry suction drills employ an injector to exhaust air from a hood or cowl that encloses the drill bit at the hole collar. Even in a wet-drilling process, in which compressed air and water are injected in the downward-flow mode, a portion of the dust generated by drilling escapes without being converted into sludge. Further, a respirable aerosol of water droplets having entrained drilling dust can be emitted.

Detonation of explosive charges in the open-pit mining of various minerals breaks up massive deposits of asbestos-bearing rock, and the blast can produce a cloud of dust that may contain asbestos fibres.(14) Similar emissions can occur when secondary blasting is used to reduce boulders to a size acceptable by the mill or to dislodge large rock deposits in open-cast mining.

In surface mining, the operations of removing overburden, scraping and shoveling of ore, preliminary screening of ore, conveying of ore, loading of ore into trucks, and the unloading of ore from trucks into hoppers at the mill can generate emissions of asbestos dust.(14) Some ores have a high moisture content (at United Asbestos, Matchewan, it is 9-10% while the average moisture content of serpentine rock is 4-5%),(73)(74) and therefore, emissions from processing these ores are less than those encountered with dry ores. The emission points associated with underground mining installations include sorting, conveying, loading, and unloading operations, which are performed on the surface outside the mines. The exhaust of ventilation air from underground mines to the atmosphere can also produce emissions.(14)

The transit of ore-loaded trucks over distances of perhaps hundreds of miles between a mine and the processing mill represents another potential emission source.(2) If the moisture content of ore hauled in open-truck bodies or the unsealed surface of roads constructed of asbestos-containing overburden or mill tailings is low, asbestos dust can be entrained by the atmosphere as the ore load is jostled and the road surface is abraded.(2)

CONTROL TECHNIQUES:

The standard techniques for dust control in other open-pit and underground mines are suitable for asbestos(2) but overall emissions from asbestos mining facilities are not stringently controlled at present. The absence of a higher degree of control is traceable to the fact that most operations are completely exposed to the atmosphere, with the result that emissions are diluted with ambient air over the relatively large surface areas such as mining pits and roads.

The atmospheric emissions that result from primary and secondary blasting in asbestos surface mining are essentially uncontrolled at present.(14) An optimum combination of amount, depth, and location of explosive charge should be sought that will produce complete combustion of the explosive compounds, along with the required loosening and breaking of a deposit, without unnecessary expulsion of material into the air. Multi-delay devices for the initiation of detonation have been used successfully at limestone quarries, but incomplete combustion of multi-delay charges, resulting from the highly fractured nature of the ore, has been observed at one domestic asbestos mine.(14)

The use of liquid or paste stemming materials in blasting holes is a promising dust control method. In European coal mines, reductions of 20 to 80 percent in dust concentrations have resulted from placing plastic cartridges filled with water, or water in combination with a wetting agent, into holes before blasting.(14) This technique has also been tested in copper mining operations. As an alternative to the use of liquid-containing cartridges, pastes with a cellulose or bentonite base can be employed.(14) Container materials and wetting agents that would not interfere with the required purity of the milled asbestos should be developed.

Effective primary blasting minimizes the need for secondary blasting and is, therefore, an indirect method of controlling emissions from secondary blasting. The use of drop-ball cranes and pneumatic or hydraulic rock splitters as substitutes for secondary blasting has proved to be effective in controlling emissions from limestone quarrying, however, the extent to which the elasticity of asbestos-bearing rock migh limit the effectiveness of drop-ball cranes for secondary fragmentation has not been fully evaluated.

Both dry centrifugal dust collectors and fabric filters have been applied to allay the dust generated during air-flushed drilling of holes for explosive charges.(14) It is well known that the collection efficiency of fabric filters, expressed on a total mass basis, exceeds that of conventional cyclone collectors. Specially designed fabric filters can be applied to pit drilling operations.

The use of wet drilling methods to control emissions has been excluded from some asbestos mining operations because of extremely cold climates or restrictions imposed by water pollution control regulations. Other types of surface mining operations have overcome prohibitively cold weather by heating water on the drilling machine and insulating the storage tank and all exposed piping. Even heated water, however, can freeze after discharge from the drill hole. Since primary drill holes are often located within 10 feet of the edge of a bench (a terraced edge of the pit), which may range from 30 to 75 feet in height in asbestos quarries, the presence of ice can pose a serious occupational hazard.(14) In warmer climates, the tendency of the drill cuttings to cement together as water seeps into asbestos seams in the fractured rock is an operational problem that limits the effectiveness of wet drilling. In the case of wet drills, smaller than those used for primary drilling, the inclusion of special design features, such as front-head release ports for the venting of compressed air or an external water feed mechanism, can control the emission of unwetted dust or respirable water-dust aerosols.

Ontario asbestos mines are subjected to very low winter temperatures. As a result, United Asbestos, in a recent application for approval of production, specified the dry drilling technique with individual bag collectors installed on each drill.(74)

The removal of overburden from ore deposits, shoveling of loosened ore, surface scraping of ore, preliminary screening and conveying of ore at the mine, and loading of ore into trucks produce asbestos emissions that are substantially uncontrolled at present. These operations, as well as primary and secondary blasting, should be scheduled to coincide as much as is practical with meteorlogical conditions favourable to the suppression of atmospheric emissions. In particular, cognizance should be taken of seasonal variations in weather conditions. The limiting of operations to periods of favourable weather conditions may occasionally be impractical because of the large amount of equipment involved and because of safety precautions requiring that blasting be carried out on the same day that the charge is loaded. The application of water or chemical sprays can alleviate emissions from ore loading in some cases.(2) Limiting factors are the possible freezing of the water or the introduction of chemicals that would interfere with the end use of the asbestos.

The atmospheric entrainment of asbestos dust emitted from loads of ore in transit from mine to processing mill can be controlled by transporting the ore in a closed-body vehicle or by fitting a flexible, impervious cover over the exposed ore load.(2) Where roadways connecting mine and mill have been surfaced with asbestos mill tailings, emissions can be reduced by periodic spraying of the roadways by water trucks.(2) Care must be taken, however, to ensure that hazardous driving conditions are not created. Tests have shown that the application of lignin sulfonate to roadways at mining facilities reduces markedly the emission of dust caused by vehicular traffic. A solution of 10 to 25 percent solid lignin in water has given the best results.(14) More recently, the application of emulsified asphalt to roads servicing open-pit mines has provided even greater emission reduction than the use of lignin sulfonate. In the planning of mining and milling operations, the possibility should be examined of reducing roadway emissions through minimizing the number of vehicle-miles by using trucks of maximum practicable capacity and by reducing the distances between mines and mills. The operating speed of vehicles is an important parameter that can affect emissions from unpaved roadways.

Asbestos emissions that result from the dumping of ore from trucks at the mill site can be abated by the use of water sprays or by the application of capture hoods or enclosures combined with gas cleaning devices. Some domestic mills currently use partial enclosure and water spraying techniques.(14)

Attempts have been made to stabilize mine overburden dumps where the waste rock, sand, and clays of hard-rock asbestos deposits are chemically neutral. These efforts have been successful to the extent that grasses and trees have been established over the surface of some waste dumps. Most areas exposed by open-pit mining, other than steep slopes, can probably be revegetated.

05.05.02 MILLING

Separation of asbestos fibers from accompanying masses of rock typically is initiated by conveying mine ore, via a large hopper and pan feeder, to a primary crusher.(14) In some instances, larger bodies of crude asbestos fibers, freed from massive rock deposits, are removed by hand-sorting at the mine. In typical commercial practice, a primary, jaw-type crusher then accepts boulders of up to 48 inches in "diameter" and reduces these to fragments with "diameters" not larger than 6 inches.(14) Subsequently, this crushed rock is transported by belt conveyor to trommel screens, which are rotating cylinders with openings of various sizes, or to a stationary-bar grizzly, a type of screen, for the sizing operation. Ore fragments of greater than 1-1/4 inch "diameter" are routed to a secondary cone-type crusher for further reduction in size, and the outputs of primary and secondary crushers are conveyed to a wet-ore storage pile exterior to the mill.(14) This stockpile usually contains a sufficient quantity of ore to sustain mill operation for an extended period of time. The above sequence of operations is illustrated in Figure 1.

In larger milling operations, wet ore is extracted from the bottom of the wet-ore stockpile by a vibrating-chute feeder located in an underground tunnel. The wet ore enters cylindrical dryers that slowly rotate to permit baffles internal to the dryers to pick up and release the wet ore continually and thereby thoroughly expose it to a drying current of hot air. This air, heated in a firebox at one end of the dryers, is forced co-currently through the dryers in the axial direction. Ore is heated typically to 110^{0}F, and a downward inclination of about 4 degrees fixes the residence time of the ore in the dryers at approximately 15 minutes.(14)

The dried ore is conveyed by belt to a vibrating screen that sizes the ore for fine crushing. Ore of more than 1-3/8 inches in "diameter" is sent to a cone crusher connected in a closed circuit with the screen, whereas the ore of particles larger than 5/8 inches and smaller than 1-3/8 inches is diverted to cone crushers that produce material of approximately 1/4 inch "diameter".(14) The undersized screenings and the output of the latter crushers form a dry-rock stockpile, which is housed so that it is protected from the exterior environment.

The finely crushed, dried asbestos ore next traverses a rock circuit. The principal purpose of this set of operations is to separate asbestos fibers from the co-existing rock, but the circuit secondarily functions to grade fibers according to length. The over-sized material from the first vibrating screen passes to fiberizers that further disintegrate the rock and release additional fibers. Undersized material from this same screen is routed to shaker screens of finer mesh; these screens are equipped with air suction (aspiration) hoods that facilitate the entrainment of asbestos fibers in an air stream and thereby separate them from the surrounding rock. This air flow conveys the asbestos to fiber-cleaning circuits. The continuation of the process is accompanied by additional screenings, air aspiration to remove freed asbestos fibers, and further rock disintegration in an impact mill.

In the rock circuit, cleaned rock is finally expelled to an exterior tailings dump. As the air streams that convey aspirated asbestos fibers are passed through cyclone collectors, the fibers are removed for cleaning and for additional grading. Exhausts from these collectors are ventilated to gas cleaning devices. At this step of the process, the asbestos fibers have been graded according to long, medium, and short lengths.

It is intended that the fiber-cleaning circuits perform additional fiber opening, classify and separate opened fibers from rock and unopened material, and carry out further fiber-length grading.(14) Initially, the fibers pass through graders constructed of perforated plates in which rotating beater arms further open the material. Undersized fractions are added to short fibers from the rock circuit, and the oversized material undergoes aspiration on shaker screens to transfer the fiber to the grading circuit. Various other stages of screening, aspirating, and opening are involved in this circuit; in addition, some material is rejected as waste. The aspirated asbestos fibers are deposited into cyclone collectors and subsequently delivered to the grading circuit as long, medium, short, and extra short fibers. As in the case of the rock circuit, the exhausts of the cyclones are directed to a gas-cleaning device.

The separation of asbestos fibers into numerous standard grades, in addition to further fiber cleaning, is accomplished in the grading circuit.(14) Standard grading machines affect additional opening of fibers and facilitate the removal of shorter fibers. The process of air aspiration from vibrating screens separates out additional fine dust, fine rock fragments, and unopened fibers. To control asbestos-containing dusts, the cyclone collectors are exhausted through fabric filters. Table 3 outlines the Canadian Chrysotile Classification System for grading asbestos fibers.

Asbestos fibers are machine packaged either by compressing the material into a dense bundle or by blowing the material into a container. The longest fiber grades are loosely packed to minimize damage to the fibers and to eliminate the subsequent necessity for excessive willowing of compressed material.

EMISSIONS

The milling of asbestos ore by a dry process requires an extensive amount of handling and subdividing of the material in both a damp and a dry state. Consequently, there are numerous potential sources of asbestos emissions at a milling facility.

The dumping of mine ore from trucks onto a wet-ore stockpile or into receiving hoppers is a potential emission source at the mill site. Further, asbestos-containing dust at the surface of an ore pile is susceptible to varying degrees of atmospheric entrainment, depending upon the moisture content of the ore and the strength of local winds.

The separating, cleaning, and grading of asbestos fibers requires large volumes of air, which are ventilated through fibric filters before being exhausted to the atmosphere or recirculated to mill buildings.(14) Because makeup air is drawn in to replace the exhausted air, process areas of a mill are frequently under negative pressure. When the volume of air exhausted to the atmosphere is sufficient for the entire mill to be under negative pressure, emissions to the atmosphere are increased.

TABLE 3

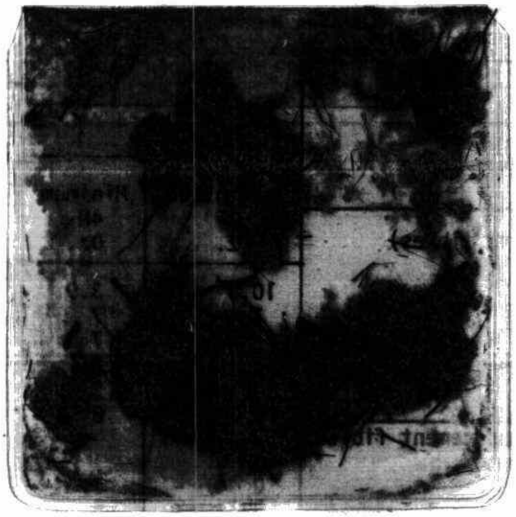
CANADIAN CHRYSOTILE CLASSIFICATION

		[illegible]	Minimum 4M Oz.	Shipping 10M Oz.	Test Pan Oz.
Group No. 1	No. 1 Crude - cross-fibre veins having 3/4 inch staple and longer.				
Group No. 2	No. 2 Crude - cross-fibre veins having 3/8 inch staple up to 3/4 inch. Run-of-mine Crude - consists of unsorted crudes. Sundry Crudes - consists of crudes other than above specified.				
Group No. 3	(Commonly referred to as textile or spinning fibres)				
3D		10[illegible]	3.9	1.3	0.3
3F		7	7	1.5	0.5
3K		[illegible]	7	4	1
3R		[illegible]	8	4	2
3T		1	9	4	2
3Z		0	8	6	2
Group No. 4	(Commonly referred to as shingle or asbestos cement fibres)				
4D		0	7.0	6.0	3.0
4H		0	5	8	3
4J		0	5	7	4
4K		0	4	9	3
4M		0	4	8	4
4R		0	3	9	4
4T		0	2	10	4
4Z		0	1.5	9.5	5
Group No. 5	(Often referred to as paper stock grades but also considered as short shingle fibres)				
5D		0	0.5	10.5	5
5K		0	0	12.0	4
5M		0	0	11	5
5R		0	0	10	6
Group No. 6	(Waste, stucco, or plaster fibre)				
6D		0	0	7	9
Group No. 7	(Shorts)				
7D		0	0	5	11
7F		0	0	4	12
7H		0	0	3	13
7K		0	0	2	14
7M		0	0	1	15
7R		0	0	0	16
7T		0	0	0	16
7RF and 7TF Floats		0	0	0	16
7W		0	0	0	16
Group No. 8	(Sand)				
8S	under fifty pounds per cubic foot loose measure				
8T	under seventy-five pounds per cubic foot loose measure				
Group No. 9	(Gravel and stone)				
9T					

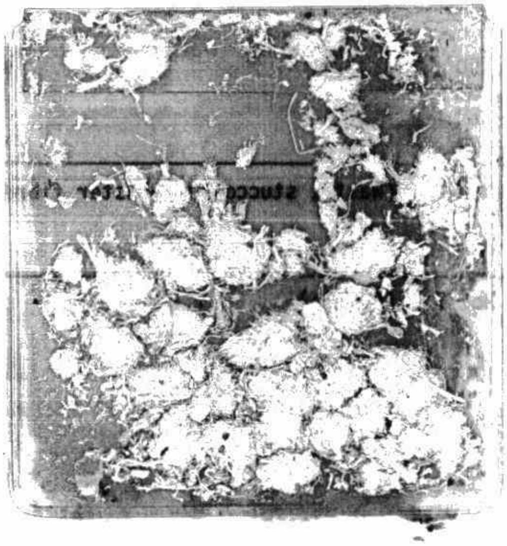
Source: (70)

ASBESTOS SAMPLES

(Courtesy of Canadian Johns-Manville Co. Ltd.)



Crocidolite (Blue) Asbestos
Grade 4D-30 (Group #4)



Chrysotile (White) Asbestos
Grade 4D-30 (Group #4)

As asbestos ore, asbestos fibers, and asbestos-containing tailings are transported among the numerous processing devices of the mill by belt conveyors, the jostling motion, combined with the large surface area of material exposed to the environment, can produce significant asbestos emissions either directly into the exterior atmosphere or into the surrounding work space. Examples of such emission sources are transportation of material from a wet-ore stockpile to a dryer, from a dryer to a grading screen, from one vibrating air aspiration screen to another, and from the undersized side of a vibrating air aspiration screen to a tailings conveyor. The potential for particularly severe emissions exists whenever asbestos-containing materials are handled at the transfer points of conveyor systems.

The severe fracturing of rock by primary and secondary crushers frees additional asbestos fibers from the ores; the accompanying mixing action of the crushers facilitates the emission of asbesots-containing dusts to the interior spaces of the equipment.(14) Because feed and discharge ports must be provided for crushers, an opportunity exists for the emission of asbestos to the exterior environment.

A large source of emissions from asbestos mills is the effluent from ore dryers.(14) The mechanical agitating action of the dryer and the necessity for contacting the ore with large volumes of air contribute to the entrainment of asbestos-containing dust in the heated gas stream. In addition to contaminants from the ore, the dryer exhaust contains a significant amount of moisture and the products of combustion from the air-heating device. The effluent temperature varies widely and can range from 140°F to 500°F.

The vibratory or oscillating motion of grading screens and the resulting sifting action of the screens as the asbestos-containing material is separated into a range of sizes expose large surface areas of material to the surrounding air; the surface of a typical screen measures 5 feet by 11 feet.(14) Accordingly, this process results in appreciable quantities of airborne dust. If there are no provisions for capturing and containing the dust, it is emitted directly into the mill work space.

Even though the packaging of asbestos fibers by machine minimizes handling and exposure of the material to the atmosphere, emissions can occur at the interface between the material and the package during the filling and sealing of containers. The packaging of fibers into coarsely woven bags or otherwise non-dust containers can yield emissions during further handling operations.

Large quantities of dry, finely divided rock that contain asbestos dust must be removed from most asbestos mills as waste material. The transfer of this rock by a moving-belt device or by vehicle to an exposed tailings dump can generate emissions to the atmosphere. Emissions can also result from the placement of tailings onto an existing dump, from the leveling of the dump to permit further deposition of wastes, and from direct entrainment of surface dust by ambient air currents.

CONTROL TECHNIQUES

To control asbestos emissions from the surface dusting of ore stockpiles, water can be sprayed onto the material from adjacent towers. This technique has also been successfully applied in the control of particulate emissions from exposed limestone stockpiles. In a typical limestone application, water is sprayed at a rate of 500 gallons per minute from towers 40 feet high; the spray covers a circle 200 feet in radius.(14) For asbestos applications, it may be necessary to use the lowest feasible flow rates in order to avoid the discharge of asbestos-containing water from the facility and to comply with applicable water pollution control regulations.

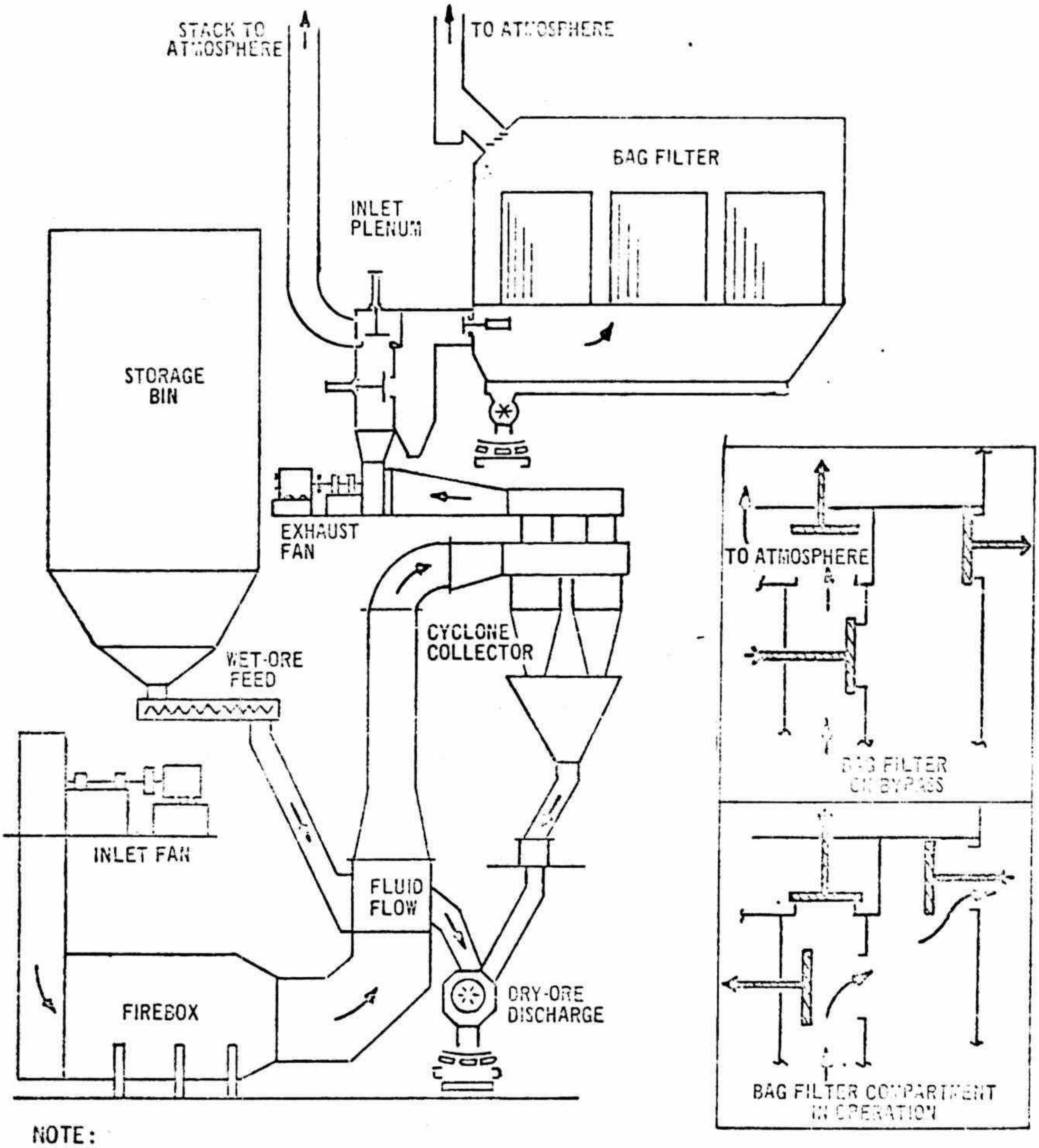
It is technically feasible to house exterior belt and bucket conveyor systems in completely enclosed galleries to prevent asbestos emissions from material in transit and from the emptied return side of the systems.(14) Furthermore, the attainment of safe occupational asbestos exposure levels may require the enclosure of in-plant conveyor systems. The asbestos milling industry is currently applying these control techniques to a limited extent. Points at which asbestos ore, asbestos fiber, and asbestos-containing waste materials are transferred between process equipment and conveyor systems, as well as conveyor system transfer points, can be hooded and ventilated to gas-cleaning devices to control emissions.

The feed and discharge ports of ore crushers can be fitted with dust capture hoods to control asbestos emissions; the hoods should be ventilated to a gas cleaning device such as a fabric filter.

Historically, cyclone collectors have been applied more widely than any other type of gas-cleaning device to control asbestos emissions from ore dryers, largely because of the relatively low initial cost, simplicity of construction, and low maintenance cost of these devices.(14) Also, the dust collection efficiency of cyclones is relatively insensitive to variations in process gas temperature and to the condensation of moisture within the collector. However, the fact that the efficiency of these dry centrifugal collectors is considerably less than that attainable with some other widely employed gas-cleaning devices has prompted attempts to gain increased collection efficiency.

Fabric filters have been successfully applied to the control of emissions from asbestos ore dryers, and it is reported that asbestos emission levels of approximately 2 X 10^6 particles per cubic foot (ppcf) have been realized.(14) Two units were in operation in Canada in 1971. Figure 2 shows an asbestos ore dryer of the fluidized-bed type and accompanying bag filter installation that was installed at a Canadian mill in 1972. The filtering chambers of these baghouses are thermally insulated to prevent excessive cooling of the effluent gas streams and the possible condensation of water; the occurrence of condensation could irreversibly cement adhering dust cakes. Orlon, Dacron, Nomex, Teflon, Terylene or Fiberglass, which can withstand the high temperatures of the gas streams, are required as filter materials.(14) Additional protection against excessively high temperatures or condensation of moisture during short time periods can be provided by the use of by-pass arrangements. Potential emissions from several processes can be controlled by dust capture hoods (ie., the grading screens, the bagging of fibers, etc.).

As one method of controlling emissions when dry, asbestos-containing mill tailings are placed on a relatively flat disposal pile, a mobile dumper is used at the end of a belt conveyor that transports the wastes. As disposal proceeds, the location of the dumper is periodically changed in order to maintain the tailings pile as nearly level as possible and thereby minimize emissions caused by shifting the tailings with earth-moving equipment. An inverted funnel mounted to the dumper discharges the wastes in close proximity to the surface of the dump in order to assist in reducing emissions at the point of deposition; however, the elimination of visible emissions at the point of deposition may also require that a water or chemical spray be used. In other milling complexes, mixtures of water and wetting agents have been applied to tailings during their discharge



NOTE:
Bag Collector
14 Compartments 50,000 cfm Each
Operating Temperature Range 170°F to 250°F
Bags of Spun Acrylic Cloth

Dryers
3/4 in. Material Dried from 10% to 2% Moistu
150 Tons/Hour

Figure 2. Configuration of fabric dust collector for ore dryer.

onto waste piles, and this has proved to be moderately successful. Visible emissions generated by the dumping of tailings have been totally eliminated at one domestic asbestos mill by the mixing of tailings with water prior to deposition. This control technique is promising for mills that have access to sufficient water and that can overcome the problem of freezing conditions.

In some cases, asbestos mill tailings form large mounds across which long belt conveyor systems with several transfer points are deployed. The transfer points can be enclosed and ventilated to gas-cleaning devices to provide emissions control. Potential emissions from segments of the conveyor system between transfer points can be controlled by enclosing the equipment.

Emissions from the surfaces of tailings dumps can be controlled by providing a protective covering or seal. Because of the large surface areas involved, most of the control methods are expensive. Whereever the eventual surface of the dump is reasonably level, soil can be spread as a sealing medium. The establishment of vegetation on dumps is hindered by the high alkalinity (pH=9) of the tailings. In preliminary tests, grass has been grown on tailings by first mixing them with the acidic tailings of a copper mine across a soil depth of about 2 inches. Chemical agents that can be sprayed onto waste dumps to form a protective surface crust that is permeable to water are commercially available. The penetration of moisture through the crust controls the potential erosion and disintegration of the cover by heavy rainfall. In some instances, tailings piles from the milling of long-fiber asbestos ores are somewhat self-stabilizing because of meteorological conditions to form a layer of larger particles that protect the interior of the pile, and the consolidation of the pile by freezing during long periods of the year.

05.05.03 ASBESTOS MINES AND MILLS IN ONTARIO

Of Canada's total mill capacity of 88,900 tons in 1970, Ontario milling comprises 6.3% of the total and by 1975, with the expected increase of production, Ontario's contribution will rise to 10.5%. Quebec mining accounts for about 80% of Canada's asbestos production.(15) Table 4 presents actual production figures for asbestos in Ontario.

A. Reeves Mine

The Reeves Mine is operated by Johns-Manville Mining and Trading Limited, a wholly owned subsidiary of Canadian Johns-Manville Company Ltd.(70) The mine is located 40 miles southwest of Timmins off Highway 101. Production started in May, 1968, milling 701,521 tons or 3,500 tons daily for the remainder of that year.(70) Production increased to 4,400 tons daily for 1969.(70)

Two pits have been in operation since 1969; the east pit scheduled to be 360 feet deep and the west pit to be about 550 feet.(70) Recently, the west pit was closed down to prepare for deeper excavation. With the proposed opening of the renovated pit, the Reeves Mine will expect to mill 5,000 tons per day.(46) Figure 3 is a photograph of the Reeves Mine, west open pit, taken in 1970.(77) (Feb.20/75, this mine closed down for an indefinite period.)

The general tenor of fibre content in the ore runs 2-1/2 to 3% with the richest ore up to 4%.(70) The bulk of the fibre produced is used in asbestos cement sewer pipe and in asphalt. Some is used in building construction (ie., paper and wallboard). Figure 4 is a photograph of the Reeves mill operation.(77)

The products of the mill are pressure packed in 100 pound bags and shipped by truck to Timmins then transferred and shipped by rail to the Johns-Manville plant in Port Credit or any of the other 8 plants in

TABLE 4

ASBESTOS PRODUCTION IN ONTARIO

ONTARIO			CANADA	
YEAR	QUANTITY	VALUE	QUANTITY	VALUE
1970	39,025 tons	$4,932,142		
1971	44,014 tons	$5,339,743		
1972	37,560 tons	$4,405,000		
1973	34,000 tons	$3,850.000	1,687,051 tons	$206,088,535

SOURCE: (76)

the United States.

B. Hedman Mine

Hedman Mines Ltd. began actual production of asbestos ore in February, 1972. Reserves of ore based on an open pit depth of 300 feet were calculated to amount to 10,300,000 tons in 1964.(70) Although there is a high proportion of extremely fine fibre veinlets, modifications in the milling technique have allowed up to 77% recovery from some of the drill core and as much as 75% from bulk samples.(70)

This open pit mine is located in Warden Township about 8 miles north of Highway 101 at a point 14 miles east of Matheson.

The ore mined from Hedman is most suitable for production of a single uniform grade of asbestos. Some of the long, higher grade fibres are sacrificed in a simplified milling technique producing a clean, uniform, short-fibre asbestos grading in group 7.(70) Its main use is as a filler in plastics. The Hedman Mill is 3/4 mile east of Matheson on the Ontario Northland Railway. Mill capacity at present is 300-600 tons/day.(15)(70) Figure 5 is a photo of the Hedman Mill near Matheson.

C. United Asbestos Inc.

Ontario's third mine/mill operation is proposed to begin production in 1975 about 17 miles west (by air) of Matachewan. The fibre is of good quality. Most of the production will be medium length fibres. The quality obtainable is well-suited for the asbestos-cement industry because of high unit strength values and very fast filtration rates. The shorter grades have good qualities for the manufacture of flooring, fibre reinforced plastics and in the dry wall cement industries.(78)

The company will mine 3,500 tons/day of ore grading 9% and

FIGURE 3.

REEVES MINE - WEST PIT

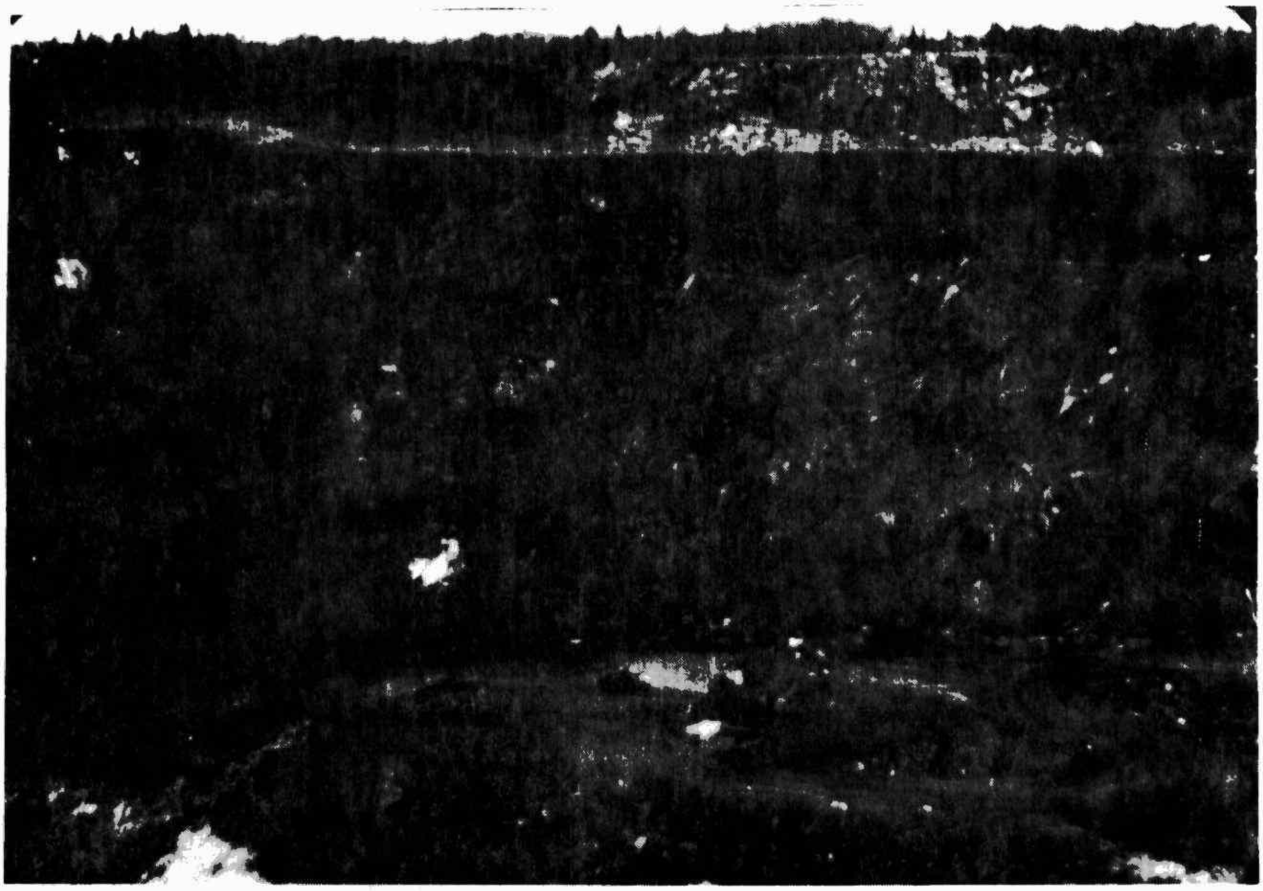


FIGURE 3. WASTE ORE DUMP - REEVES MINE

(Courtesy of Dr. M.A. Vos)[77]

FIGURE 4.
REEVES MILL OPERATION

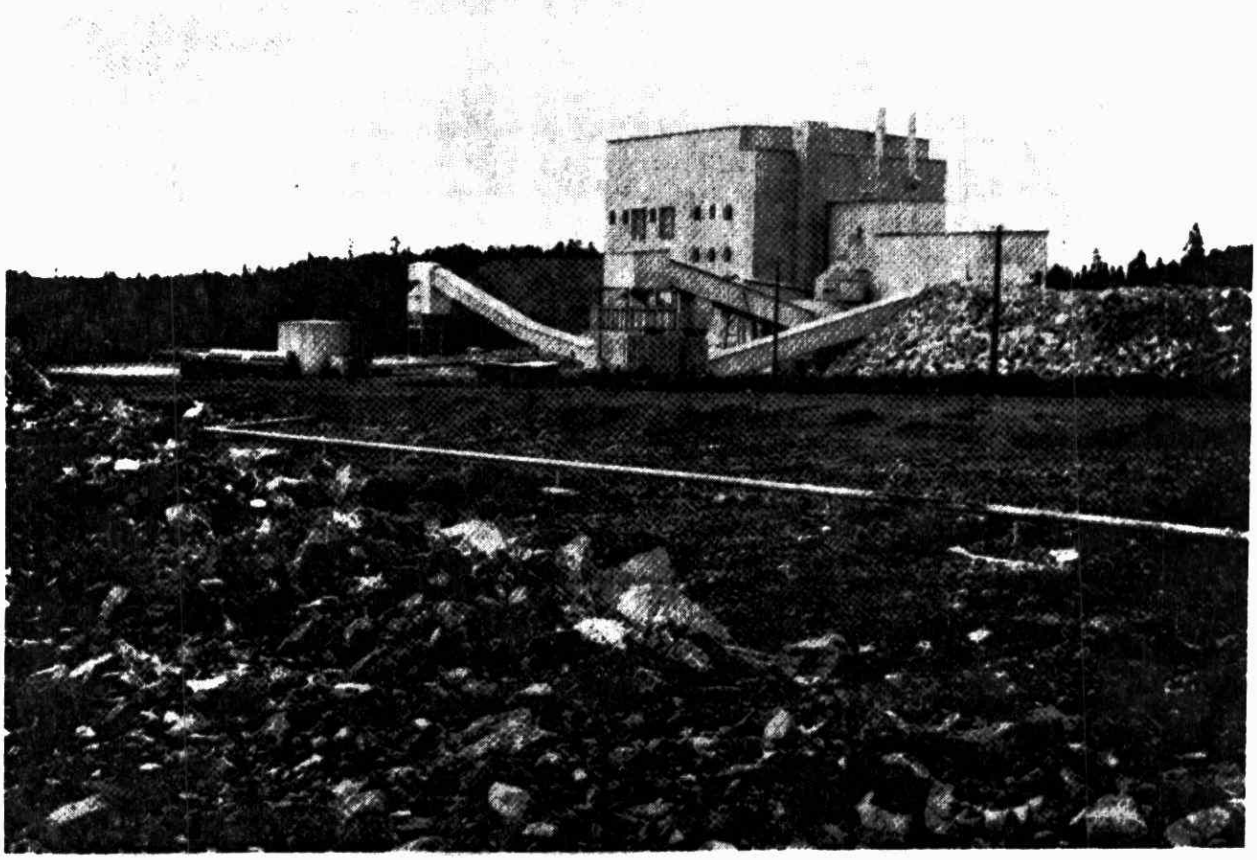
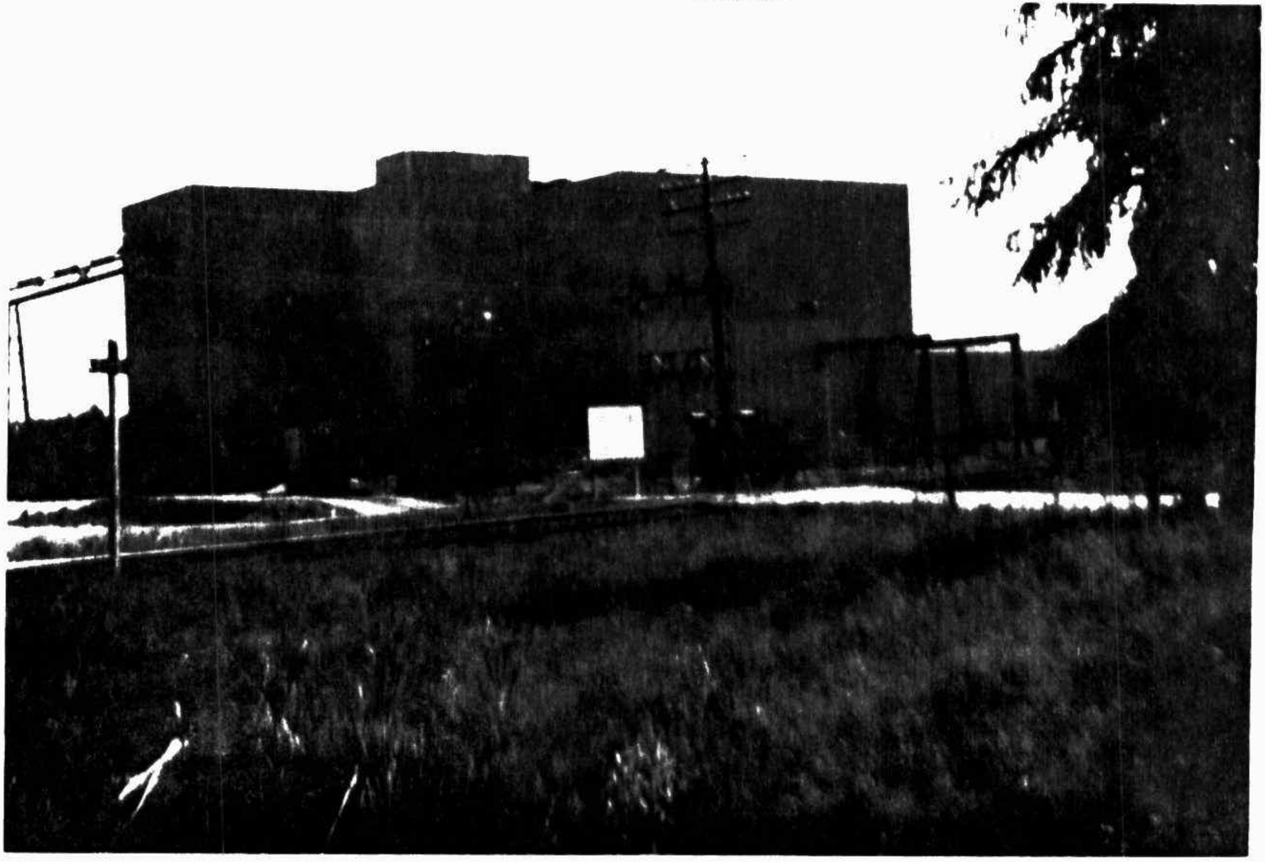


FIGURE 5.
HEDMAN MILL OPERATION NEAR MATHESON



(Photographs Courtesy of Dr. M.A. Vos)(77) extracting 300 tons/day of fibre (100,000 tons/year).(16)(78) Tentative marketing studies indicate that 30% of production will go to Europe, 30% to the Far East and 40% will be marketed in North and South America.(78) The Matchewan facilities can be readily expanded to 200,000 tons/year of fibre as overseas customers buy more products.(16) The ore body contains an estimated 31 million tons of ore, enough for 30 years at a 3,500 tons/day consumption rate.(16) Additional resources may be developed when the mining of the serpentine rock under Lake Lloyd eventually becomes feasible.(78)

05.05.04 EMISSION FACTORS

Emission factors for mining and milling operations are difficult to estimate so, consequently, reported values vary widely. Mining and milling asbestos operations are suspected of being a large source of ambient emissions,for obvious reasons. Davis and Associates estimate an emission factor for the mining and milling operations of 93 pounds per ton of asbestos produced based on data in Table 5.(13) They estimate that for the year 1968, asbestos emissions for both processes were 5,610 short tons in the United States.(13)

James F. MacLaren Ltd. of Toronto applied emission factors complied by the Environmental Protection Agency (EPA). A handling loss figure of 2 pounds/ton was applied to loading and unloading operations and an additional 4 pounds/ton for dust losses during drilling, blasting, and transporting.(15) On the basis of this 8 lb/ton emission figure, atmospheric emissions from asbestos mines in Ontario using proposed milling rates for 1975 will be 33.32 tons.

James F. MacLaren Ltd. break down the milling process into 4 major emission categories. The principal area of concern to the asbestos industry has been the atmospheric emissions from the dryer stack.(41) From

TABLE 5

ASBESTOS EMISSIONS FACTORS FOR MINING AND MILLING*
(pounds per tons of asbestos produced)

	Uncontrolled	Cyclone	Baghouse	Emission Factor
Mining	X			3
Loading	X			2
Hauling	X			2
Unloading	X			2
Crushing & Drying		X		10
Milling		X	X	64
Tailings	X			10
				93

*Based on baghouse efficiency @ 99.5% and cyclone efficiency @ 80%.

SOURCE: (13) in References.

data received, James F. MacLaren Ltd. estimated an average loss figure of 1.4 pounds/ton (controlled). Mill exhaust losses (through air aspiration processes, etc.) were established by assuming that 20% of the asbestos produced escapes the cyclone separators and 1% of this figure escapes the baghouse. The overall lower-limit loss indicated is therefore 0.2% of production or 4 pounds asbestos/ton produced.(15) An upper limit was estimated at 20 pounds/ton but a 10 pounds/ton factor was used.(15)

Additional asbestos dust is created during crushing and conveying of asbestos ore. The Environmental Protection Agency suggests a total of 11.2 pounds/ton suspended emissions from the various crushing and screening operations plus an additional 2 pounds/ton for conveying and handling losses.(15) Assuming the use of a bag filter with 99% efficiency leads to an additional emission factor of 13.2 X 0.01 = 0.1 lb/ton asbestos milled.(15) A fourth source of asbestos emission is the dust released from the disposal of tailings. The E.P.A. storage pile emission factor is 10 lb/ton.(15) Assuming a 0.1% asbestos content in the waste rock, James F. MacLaren Ltd. estimates an emission of 0.02 lb asbestos/ton of tailings.

Table 6 lists emission factors for asbestos mining and milling operations prepared by the Environmental Protection Agency.

TABLE 6

EMISSION FACTORS FOR ASBESTOS FROM MINING AND MILLING[a]

Source[b]	**Emission factor** lb/ton of asbestos produced
Mining, total	9 to 10
Mining	3
Loading	2
Hauling	2
Unloading	2
Mining, total, 50% control	5
Milling	100
Milling, 50% control	80
Milling, 80% control	20

[a] The emission factors are based on engineering estimates and no source sampling. These factors cannot be used to quantify asbestos emissions with great accuracy.

[b] Uncontrolled unless otherwise specified.

SOURCES: Emission Factors for Trace Substances
U.S. Environmental Protection Agency
EPA-450/ 2-73-001

(52) in the References.

05.06 MANUFACTURING OF PRODUCTS CONTAINING ASBESTOS

05.06.01 ASBESTOS-CEMENT PRODUCTS -

Asbestos-cement products comprise by far the largest single domestic use of asbestos containing 10% to 25% by weight of asbestos,(3)(15) mostly of the chrysotile variety. Crocidolite is used to a limited extent, whereas the use of amosite is limited because of its lower tensile strength. Asbestos-dement pipe composes the largest part of the asbestos manufacturing industry. Typical applications involve transport of the following materials:(14)

(1) Potable, drainage, and irrigation water

(2) Sewage

(3) Industrial products

(4) Air and other gaseous substances for heating, cooling, and gas venting.

Other asbestos-cement products, such as siding shingles and flat or corrugated sheets, are used in a variety of applications.(1)(5)

The interwoven structure formed by the asbestos fibres provides a reinforcing medium by imparting increased tensile strength to the product, the result being a 70-80% decrease in weight.(14) But, the asbestos must be embedded in the product in a completely fiberized or willowed form.

Asbestos-cement products are manufactured by:

(1) moulding process (for articles of irregular shape)

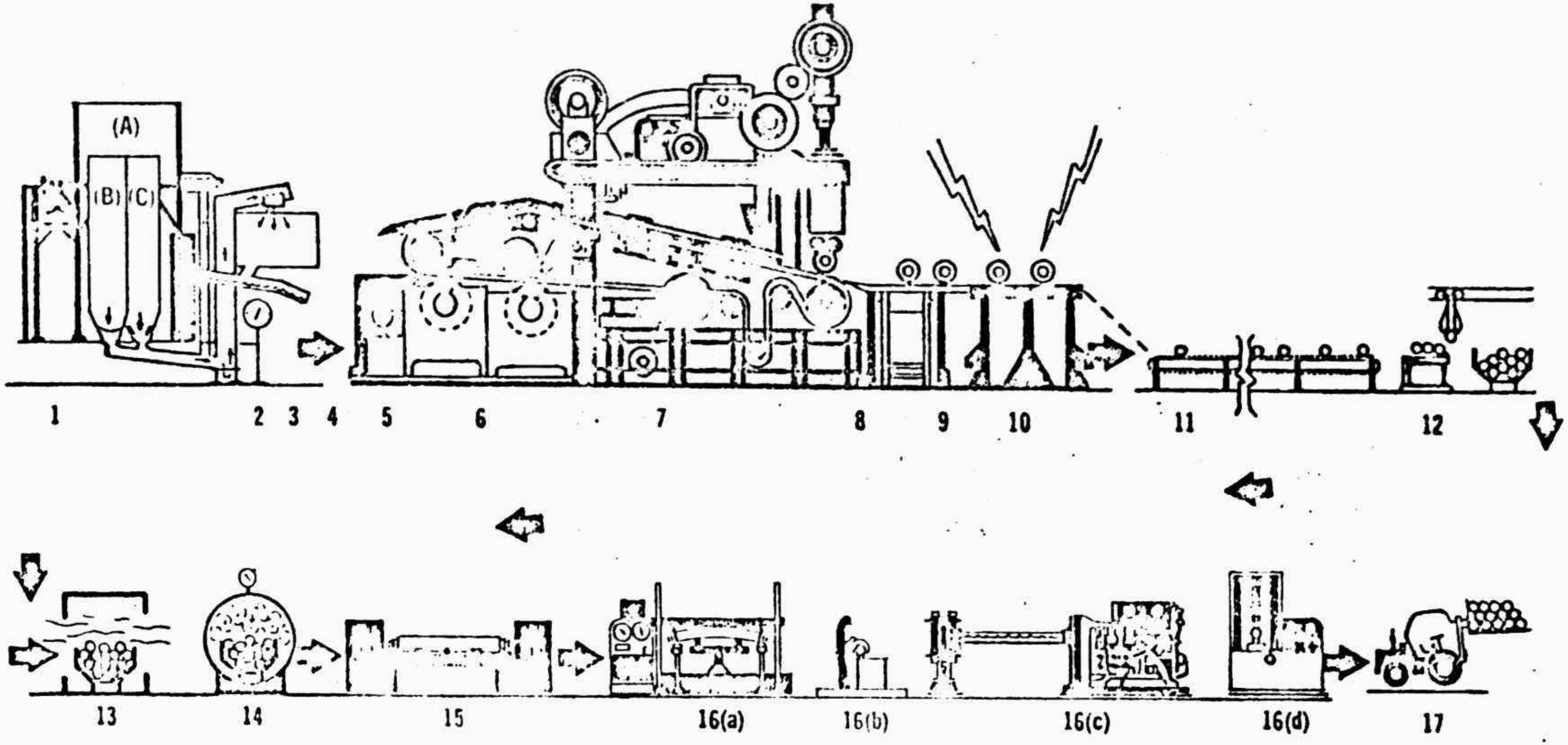
(2) dry process (sheeting products but not used much)

(3) wet process (asbestos pipe mostly)

(4) wet mechanical process (asbestos pipe mostly)

Figure 6. shows a flow diagram of the manufacture of asbestos-cement pipe using the wet-mechanical process. The equipment is similar in principle to some paper manufacturing machines. In Figure 6., the fluffed and separated fibre is transferred to a production line bin, weighted and mixed with silica and cement, conveyed by a water stream to a wet mix vat, formed into a homogeneous slurry, and delivered to cylinder vats for deposition onto one or more horizontal screen cylinder molds. Gravity-dried of excess water through the fine wire mesh screen that forms the circumferential surface of each mold, the asbestos forms a layer of asbestos-cement material, 0.02 to 0.10 **inches** thick.$^{(14)}$ The layer from each mold is transferred to an endless felt conveyor in order to build up a single sheet for further processing. The sheet is further dried in a vacuum box and transferred to a mandrel, or accumulator roll, which winds the sheet into pipestock of the desired thickness. The pipe section wrapped around the mandrel is removed from the machine and then freed from the mandrel by an electrolytic loosener.$^{(14)}$ Precure time is provided by a slow-down conveyor before the mandrel is removed and the pipe is stenciled for identification. The pipe is transported to a temperature and humidity controlled air-cure room before entering the autoclaves where high-pressure steam curing imparts maximum strength and chemical stability.$^{(14)}$ The pipe sections are machined to size on lathes, tested and transferred to the shipping area.

Asbestos-cement products are strengthened by one of three curing procedures: wet curing, atmospheric steam curing, and autoclave curing.$^{(13)}$ The oldest procedure, wet curing, is carried out in a warm humid atmosphere for 21 to 28 days.$^{(14)}$ Subsequent storage under water for 7 days, frequently performed in the wet curing of asbestos-cement pipe, produces additional strength. Atmospheric steam curing is a form of wet



1. PRODUCTION LINE BINS
    (A) ASBESTOS
    (B) CEMENT
    (C) SILICA
2. ELECTRONIC SCALES
3. DRY MIXER
4. CONVEYING TROUGH
5. WET MIX VAT
6. SCREEN CYLINDER MOLD
7. VACUUM BOX
8. FELT DEPOSITS STOCK ON MANDREL
9. MANDREL (WITH PIPE)
10. ELECTROLYTIC LOOSENER
11. SLOW-DOWN CONVEYOR
12. STENCILLING STATION
13. AIR CURE ROOM
14. AUTOCLAVES
15. LATHES
16. TESTING EQUIPMENT
    (A) FLEXURE TESTING MACHINE
    (B) INSPECTION
    (C) HYDROSTATIC TESTER
    (D) CRUSH TESTER (LABORATORY)
17. MATERIALS HANDLING EQUIPMENT

FIGURE 6. Flow Chart for Manufacture of Asbestos-Cement Pipe

curing in which steam at atmospheric pressure is used to accelerate the wet curing process. In autoclave curing, pressurized steam (100 to 250 pounds per square inch) is used to accelerate the process and initiate the chemical reactions that harden the product.(53)

EMISSION SOURCES

Significant amounts of asbestos can be emitted throughout manufacturing processes where the asbestos is not thoroughly wetted.(14) Operations that precede the inclusion of asbestos in a wet processing mixture (ie., the possible generation of asbestos-containing emissions when bags of asbestos are opened, the fibre is dumped into a blender, blended, willowed, transferred to raw material storage bins, etc.) have high potential emission rates. Wastes dispersed in a wet condition in the vicinity of processing machinery can become emission sources if they are not removed prior to drying. Also, large quantities of dry, asbestos-containing dust are produced when the ends of cured pipe sections are machined to ensure proper mating with connectors.

CONTROL TECHNIQUES -

Potential emissions from almost all the manufacturing processes can be controlled by the application of local dust capture hoods. A fabric filtering device can then control emissions to the atmosphere. Also, asbestos fibres have been conveyed pneumatically from a willow to production line feed bins. This method, in conjunction with a gas cleaning device for the conveying air stream, can control emissions that would otherwise accompany the transport of dry, loosely bound material on an open conveyor system.

EMISSION FACTORS -

Data regarding the magnitude and nature of asbestos emissions

TABLE 7.

CANADIAN EMISSIONS FROM THE MANUFACTURE OF ASBESTOS GOODS (1970)

Industry	Asbestos consumption (1000 tons)	Emission factor (lb/ton)	Emissions tons	Emissions %
Asbestos-cement products	25.0	0.15	1.88	34.7
Floor tile	10.0	0.15	0.75	13.8
Paving	5.8	0.15	0.44	8.1
Coatings, caulks, sealants	5.6	0.15	0.42	7.7
Insulation	3.8	0.3	0.57	10.5
Friction materials	2.2	0.9	0.99	18.2
Plastics	1.2	0.15	0.09	1.7
Textiles	0.7	0.30	0.11	2.0
Papers	0.7	0.15	0.05	0.9
Miscellaneous	1.7	0.15	0.13	2.4
TOTAL	56.7		5.43	100.0

Source: (15) in the References.

to the atmosphere from asbestos-cement plants is scarce. Davis and Associates presented an emission factor based on visual inspection estimated at 1 pound per ton of asbestos processed.(13) Based on this, they calculated that, for 1968, asbestos emissions to the atmosphere due to the manufacture of asbestos-cement products was 205 short tons.(13) This data is summarized on Table 8. Using scanty emission data, James F. MacLaren Ltd. computed several emission factors and on the basis of the similarity of processes and controls in the manufacturing industries involved, an emission factor of 0.15 lb/ton was considered to be representative of most asbestos manufacturing plants engaged predominantly in the wet processes.(15) As can be seen from Table 7., this amounts to 1.88 tons of asbestos emitted to the Canadian atmosphere due to asbestos-cement processing. The E.P.A. in the United States estimates an emission factor of 1 lb/ton of asbestos produced, as can be seen from Table 9.

The rate of growth of demand for asbestos-cement products in Canada is expected to decline in the next few years because of competition from other materials.(15) Small diameter plastic pipe has replaced asbestos-cement pipe in many applications.

05.06.02 ASBESTOS TILE -

Vinyl-asbestos floor tile, which contains 25% asbestos by weight,(14) is widely used in residences, schools, public buildings, theatres, and exhibition halls.(14)(15) The attractive features of this product are its non-combustibility, resistance to water and dampness, and its high strength.(15)

Various mixers, for example, those of the Banbury type, are employed to knead the raw materials of plasticized resin binder, asbestos fibres, ground limestone, and pigments into a heated batch of base material.(14)

TABLE 8.

AMERICAN ASBESTOS EMISSIONS

1968

SOURCE CATEGORY	SOURCE GROUP	SHORT TONS	EMISSION FACTOR (LB/TON)
Mining and other Basic Processing	Mining and Milling	5,610	93 C
Reprocessing	Friction Materials	312	6 C
	Asbestos Cement Products	205	1 C
	Textiles	18	2 C, 40 NC
	Paper	15	1 C, 4 NC
	Floor Tile	100	1 C, 4 NC
	Miscellaneous	28	
Consumptive Uses	Construction	61	
	Brake Linings	190	10 NC
	Steel Fireproofing	15	10 NC
	Insulating Cement	25	25 C
Incineration or Other Disposal		NA	NA
	TOTAL	6,579	

NA - Data not available

C - Controlled

NC - Not controlled

Source: (13) and (52) in References.

TABLE 9.

EMISSION FACTORS FOR PROCESSING OF ASBESTOS[a]

Source[b]	Emission factor, lb/ton of asbestos processed
Friction material, controlled	6
Asbestos cement products, controlled	1
Textiles	40
Textiles, controlled	2
Asbestos paper	4
Asbestos paper, controlled	1
Floor tile	4
Floor tile, controlled	1

[a] The emission factors are based on engineering estimates and no source sampling. These factors cannot be used to quantify asbestos emissions.

[b] Uncontrolled unless otherwise specified.

Source: Emission Factors for Trace Substances,
U.S. Environmental Protection Agency,
EPA-450/ 2-73-001

(52) in the Bibliography.

After the base material has been decorated by adding granules of the proper shapes and colors to the material as it passes through a two-roll differential speed mill, the relatively thick sheet is cut and joined to a similar piece that has been previously formed and is in the process of being calendered (smoothed and reduced in thickness between two revolving cylinders).(14) The sheet then traverses a two-roll calender that reduces the sheet to a thickness slightly greater than that of the finished tile. The manufacturing process at this stage is continuous, as opposed to batch. The passage of the tile sheet through a second, and sometimes a third, two-roll calender produces tile of the desired thickness and surface finish. Subsequently, a blanking press die cuts tiles to final size before cooling and hardening of the compound.(14) Waste material is recycled to the mixing operation for immediate reworking. A flow diagram of a typical vinyl-asbestos floor tile manufacturing operation is illustrated in Figure 7.

SOURCES OF EMISSIONS -

Specific potential emission sources of the asbestos tile process include the handling of packaged asbestos from receiving location to bag-opening site, opening and emptying of bags into raw material bins, dry mixing of the tile compound and discharge of the dry mixture into the kneading apparatus to start the actual manufacturing process.(14) Because the tile is processed as a mass of semisolid material, emissions are limited primarily to these initial operations. Semisolid wastes, however, can generate emissions if they are not removed from the work areas.

CONTROL TECHNIQUES -

Dust capture hoods can be employed to ventilate bag opening and dumping areas, dry-mixers, and equipment for crushing scrap material in the manufacturing process. The gas stream can be cleaned by passing them through fabric filtering devices before exhausting the dust control

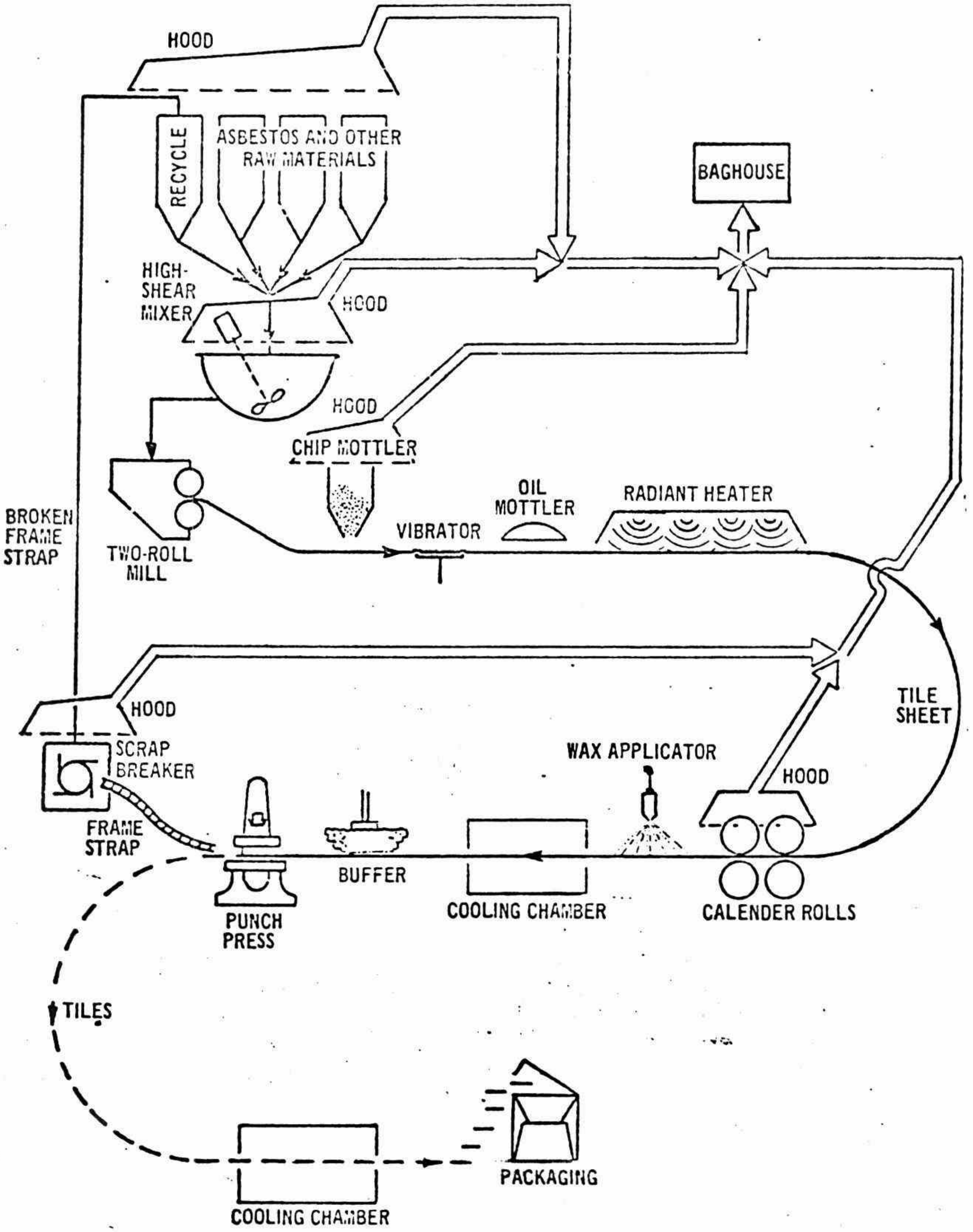


FIGURE 7. Flow Chart for the Manufacture of Vinyl-Asbestos Floor Tile

air streams into the atmosphere.

EMISSION FACTORS -

Davis and Associates estimate the use of asbestos in the production of floor tile at 200,000 short tons in 1968 in conjunction with an emission factor of 1 lb/ton,(13) whereas James F. MacLaren Ltd., using their basic emission factor of 0.15 lb/ton, calculate a total emission figure for Canada in 1970 of 3/4 tons.(15) The E.P.A. has estimated that 1 pound of asbestos is emitted per ton used (controlled) or 4 lb/ton uncontrolled for this manufacturing operation.

The total amount of asbestos used for the production of floor tiles has not changed much during the past few years.(13) The demand for asphalt tiles is decreasing to the point where they are no longer produced in Canada.(13)(15) More asbestos is being used for vinyl-asbestos flooring in Canada and the United States but, due to competition from carpets and other floor coverings, the future outlook for the industry is stable with no rapid growth anticipated.(13)(15)

05.06.03 ASBESTOS PAPER -

Asbestos paper, containing chrysotile as the principle type of asbestos, has a wide variety of uses, Table 10. indicating the extent of the applications.(54) Frequently, product requirements dictate that other materials be combined with the asbestos paper. For example, asbestos paper is impregnated with asphalt to form asbestos felt roofing and pipe wrapping. A primary user of asbestos paper is the electrical equipment industry in which the paper serves as a low-cost, thin spacing material that processes desirable electrical insulating and heat resistant properties.(14)

Figure 8. shows the manufacturing process of asbestos-paper

TABLE 10.

USES OF ASBESTOS PAPER

- Air cell and other pipe coverings
- Boiler jackets
- Asbestos roofing felt
- Asbestos-protected metal roofing
- Gaskets (plain & metal reinforced)
- Wicks in oil burning apparatus
- Tubes for electrical insulation
- Electrical insulation of wire and cable
- Insulation of hot air pipes
- Linings for stoves & heaters
- Linings for filing cabinets, cartridges, carpets, auto mufflers, drum controllers, cookers, electrical appliances, armored car roofs, motors, etc.
- Drip catchers in enameling ovens
- Insulation for ovens and dry kilns
- Table pads and mats
- Insulation in heat- and chemical-resistant reinforced plastic pipe and other laminated products
- Diaphragms in electrolytic cells
- Tank covers
- Filters
- Protection from heat and other welding processes
- Crumbled paper in annealing
- Insulation in chemical and physics laboratories
- Insulation for automobile exhausts
- Clutch facings in automatic transmissions
- Baking sheets
- Hot-air ducts or linings of paper ducts for hot air service
- Base for floor covering
- Saturated paper for cooling tower fills

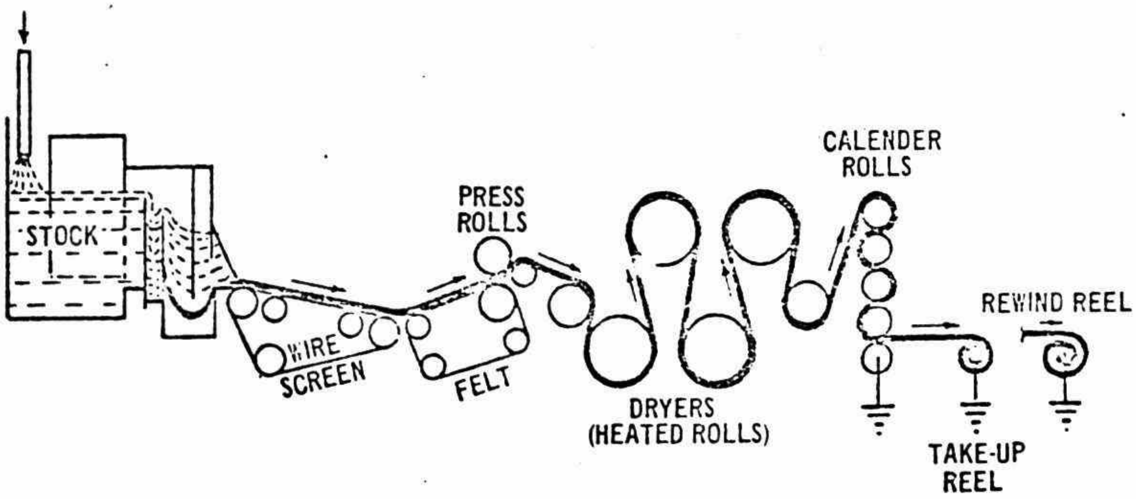


FIGURE 8. Asbestos Paper Manufacturing (Fourdrinier Paper Machine)

using a Fourdrinier machine.(53) The mixing operation combines 6% to 12% short fibre asbestos(14) with binders (starch, glue, waterglass, resins, latex, cement and gypsum) selected for the desired properties and application of the paper.(55) A pulp beater, or Hollander, mixes the asbestos, binder, and water into a stock that is diluted to as little as 1.5% fibre in the discharge chest.(14) From here, a thin uniform layer of the stock is deposited by gravity onto an endless moving wire screen through which a major portion of the water is removed. The sheet is then transferred onto an endless, moving felt and pressed between pairs of rolls to bring the paper to approximately 60% dryness.(14) Subsequently, the continuous sheet of paper passes over heated rolls, while supported on a second felt, to effect further drying. This is followed by calendering of the paper to produce a smooth surface and cutting the paper to size as it is wound onto a spindle.

EMISSION SOURCES

In addition to the emissions that occur during handling operations as asbestos is brought to the preparation end of a paper machine, there are potential emissions from the mixing of ingredients in a pulping mill.(13) Since this mixture is next converted into a thin slurry for further processing, the potential for the subsequent emission of asbestos into the work space is diminished until the paper has been dried.(14)(15)

CONTROL TECHNIQUES -

Again, high-volume, low-velocity dust capture hoods will control asbestos emissions and passage to a fabric filtering device provides control of potential atmospheric emissions.(14) Additional control can be provided by the use of pulpage bags that can be added to the mix (which obviates the need to open the bags).

EMISSION FACTORS -

Davis and Associates estimated the quantity of asbestos used in paper in the United States during 1968 at 30,000 short tons, emitting one pound for every ton of asbestos processed.(13) Parallel Canadian estimates show that of the estimated 700 tons of asbestos consumed to produce the product, 400 pounds were emitted.(15) The E.P.A. (Table 9.) reports an emission factor of 1 lb/ton (controlled) and 4 lb/ton (uncontrolled).

05.06.04 FRICTION MATERIALS CONTAINING ASBESTOS -

Asbestos containing friction materials are used extensively in the fields of transportation, mining and heavy construction. Specific applications are of drum, disk, outerjaw, and band brakes and in dry and oil-immersed clutches.(13)(15) The classes of bonding materials are drying oils, plastics, bitumens and natural and synthetic rubbers.

The desirable characteristics of friction materials are the maintenance of a constant coefficient of friction under varying contact stress, moisture, and temperature in combination with minimum wear of the friction material and corresponding bearing surface.(13) Although all common friction materials become inoperative when immersed in water, the materials are designed to shed the water quickly and recover fully.(14) The variety of asbestos predominantly used is chrysotile.(13)(14)(15)

Figure 9. shows the manufacture of dry-mixed molded brake linings and Figure 10. shows brake linings and clutch facings. Figure 11. describes the manufacture of woven brake linings and Figure 12. diagrams the manufacture of endless wound clutch facings. In order to supply brakes for an annual brake lining replacement market in excess of 25 million vehicles, more than 500 brake relining companies in the United States use the

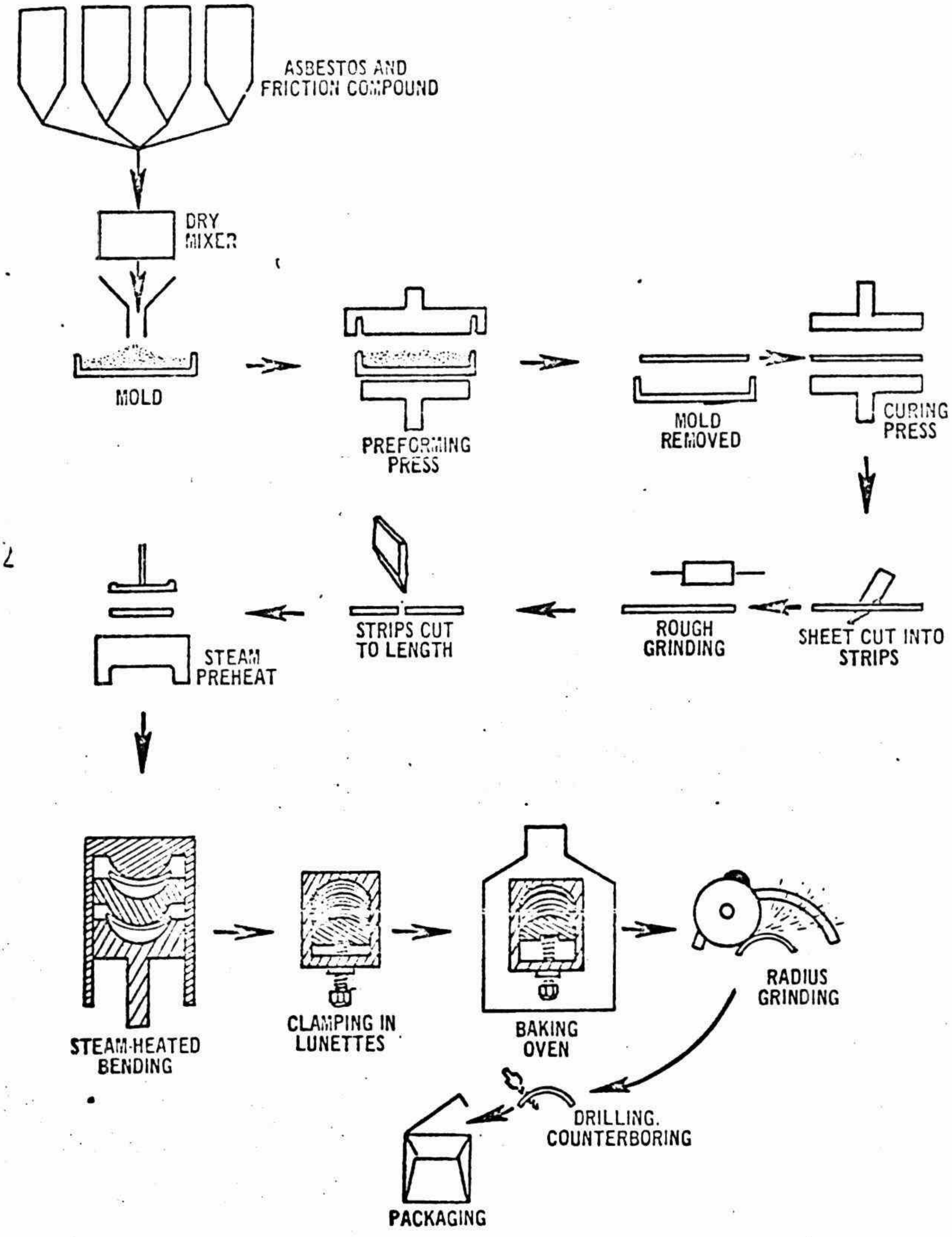


FIGURE 9. Manufacture of Dry-Mixed Molded Brake Linings

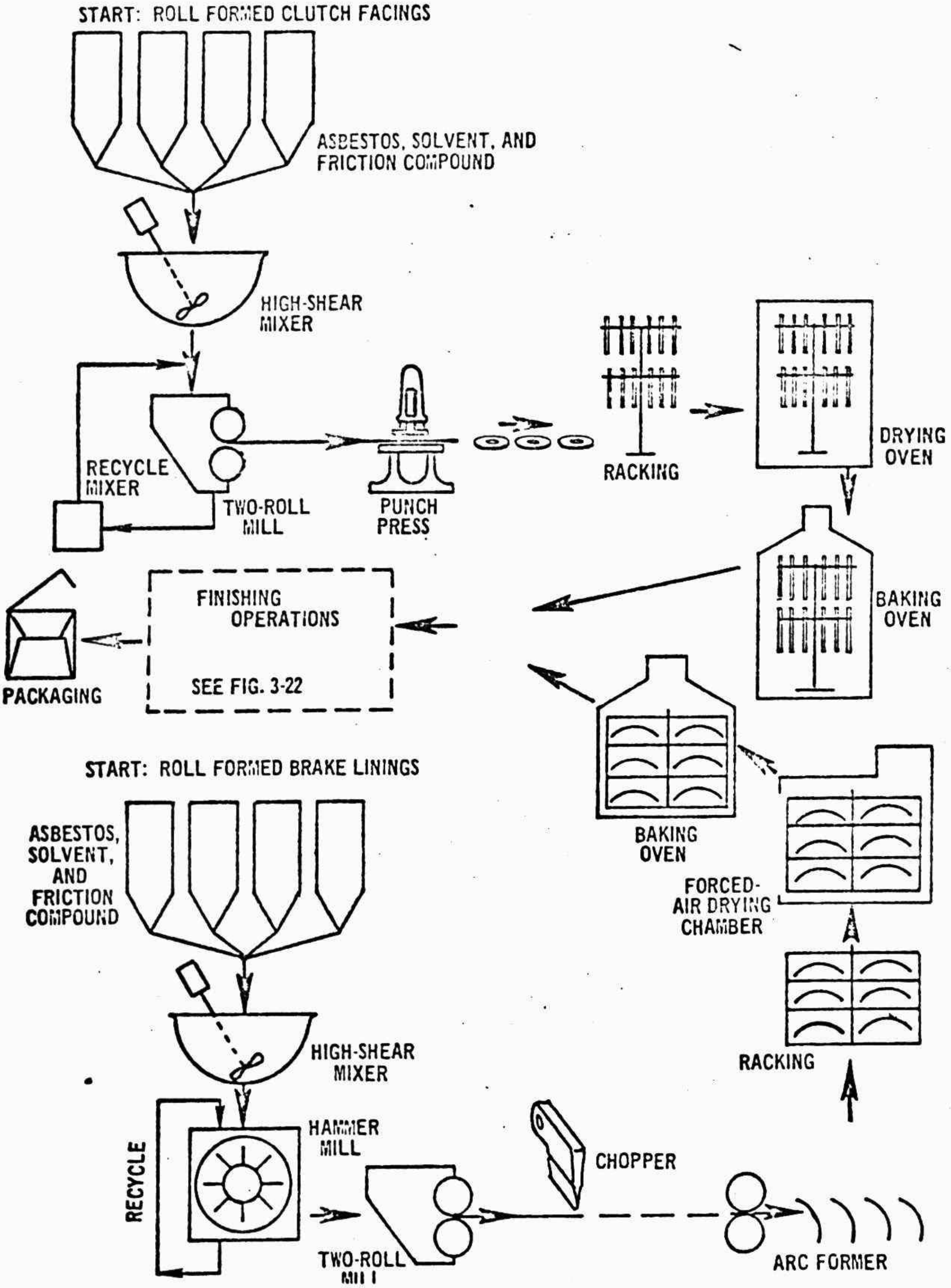


FIGURE 10. Two-Roll Forming of Brake Linings and Clutch Facings

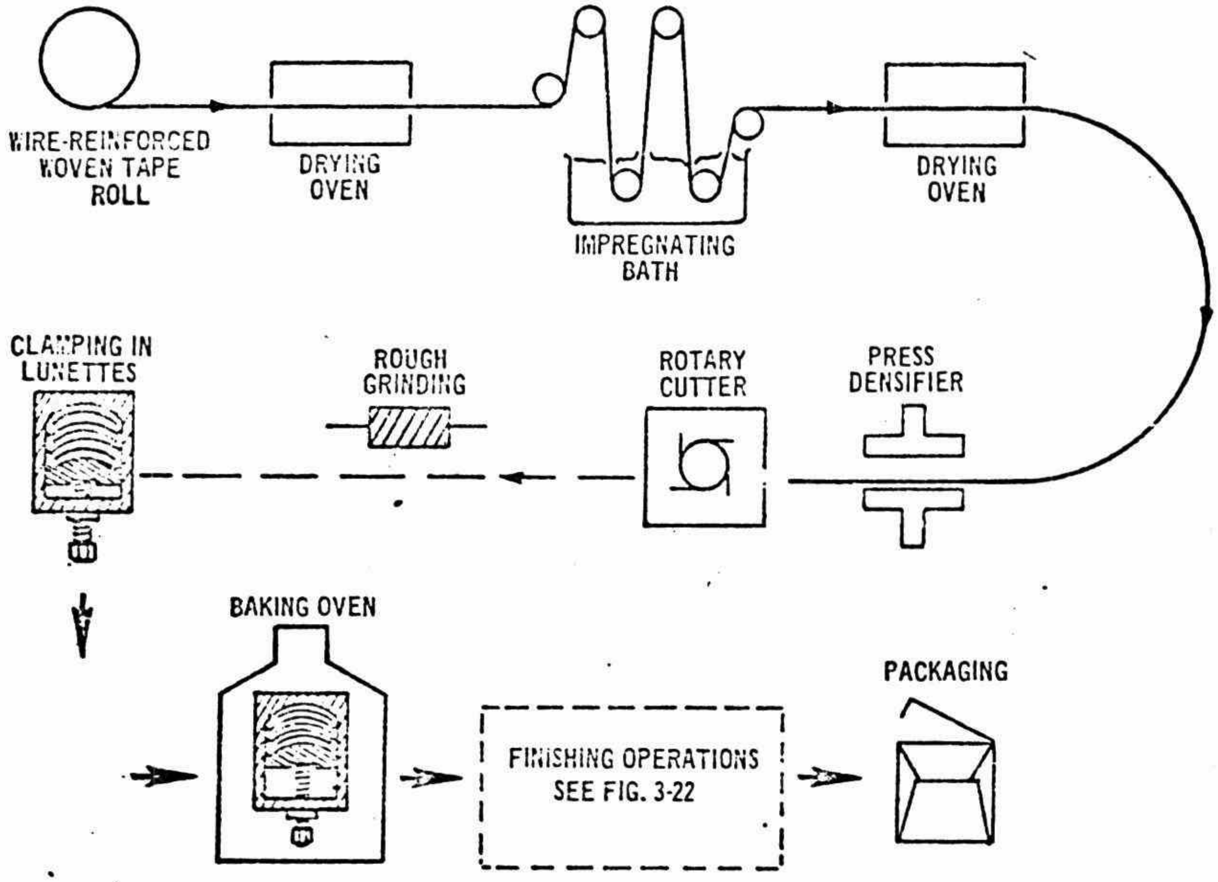


FIGURE 11. Manufacture of Woven Brake Linings

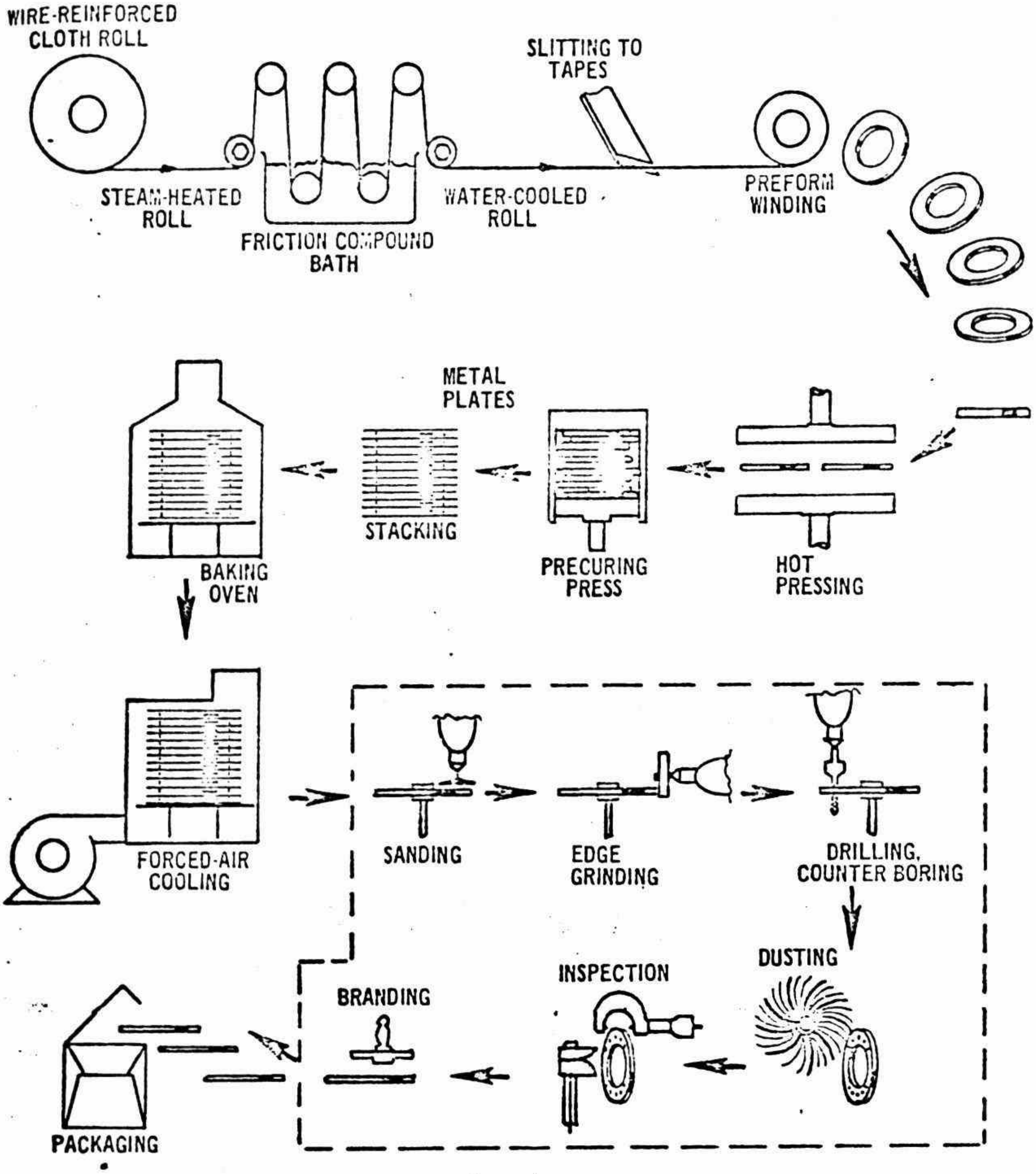


FIGURE 12. Manufacture of Endless Wound Clutch Facings

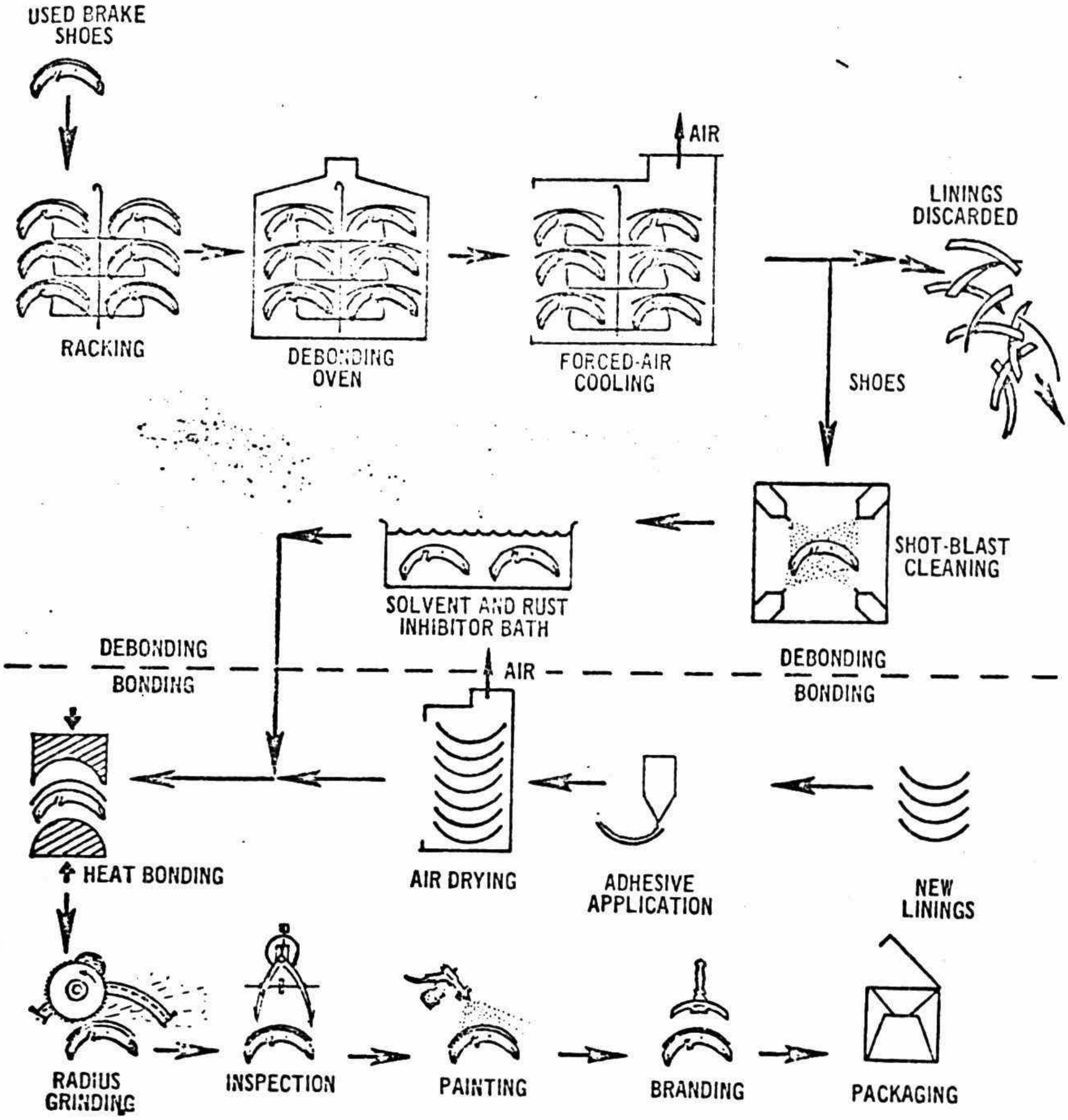


FIGURE 13. Process of Debonding and Bonding Brake Shoes

process described in Figure 13.

EMISSION SOURCES -

Aside from emissions related to the handling of asbestos in bags, operations that involve asbestos in certain dry-mixed molding compounds (such as weighing of raw materials, charging of mixers, blending of component ingredients, and discharging of mixers) are major potential emission sources in the production of friction products. Finishing operations, however, can generate much greater quantities of asbestos-containing dust from the use of band saws, abrasive wheels, drills, cylindrical grinders, disk grinders and circular saws.(14) For example, the drilling and grinding of brake linings during manufacture release as much as 30% of the lining material as waste.(13) Brake debonders are not considered to be major sources of asbestos emissions since the adhesives are burned without any physical disruption of the surface integrity of the brake linings.

CONTROL TECHNIQUES -

As in the manufacture of numerous other asbestos-containing products, emissions from the production of asbestos friction products are controlled by applying dust capture hoods of both low-volume, high velocity and high-volume, low velocity types. Dust in the air streams again is cleaned with fabric filtering devices.

EMISSION FACTORS -

In the United States, the use of asbestos in friction materials during 1968 was about 104,000 short tons.(13) The survey conducted in 1968 by Davis and Associates revealed a large manufacturer of brake linings who reported the use of 4,000 tons of asbestos, estimating overall atmospheric emissions of asbestos to be 0.25% to 0.50%.(13) The efficiency of his bag filter collection equipment must be 99.5 - 99.75%. The estimated emission factor of 6 lb/ton of asbestos processed presents asbestos emissions into atmosphere of approximately 312 short tons.(13)

Since there is substantial dry grinding in the manufacture of friction materials, James F. MacLaren Ltd., as well as Davis and Associates, accordingly estimate an emission factor six times that of other industries (0.15 X 6 = 0.90 lb/ton).(15) With this information, the Canadian consumption of 2,200 tons of asbestos for friction materials, results in the emission of 1 ton.(15)

The E.P.A., as can be seen in Table 9., considers the emission factor to be 6 lb/ton of asbestos processed in friction product manufacturing.

05.06.05 ASBESTOS TEXTILE PRODUCTS -

The properties of asbestos (ie., strong resistance to heat, fire, acids, and mechanical abrasion) make this fibre ideal for particular textile applications. The fibres must be long, fine and flexible with a superior tensile strength.(13)(15) Although chrysotile is the dominant variety, crocidolite and amosite are also used.(14) The more common products are roving, carded lap, yarn, cord, rope, square-plaited goods, braided tubing, tape, webbing, cloth.(13)(14)(15) The asbestos content usually ranges from 75-99%.(13) Only milled fibres are used and sometimes the milling device is located in the plant (this can have serious emission potential). The fibres are then introduced to vibrating screens where the fibres are removed by an air aspiration system and graded.(14) The process then follows the outline described in Figure 14.

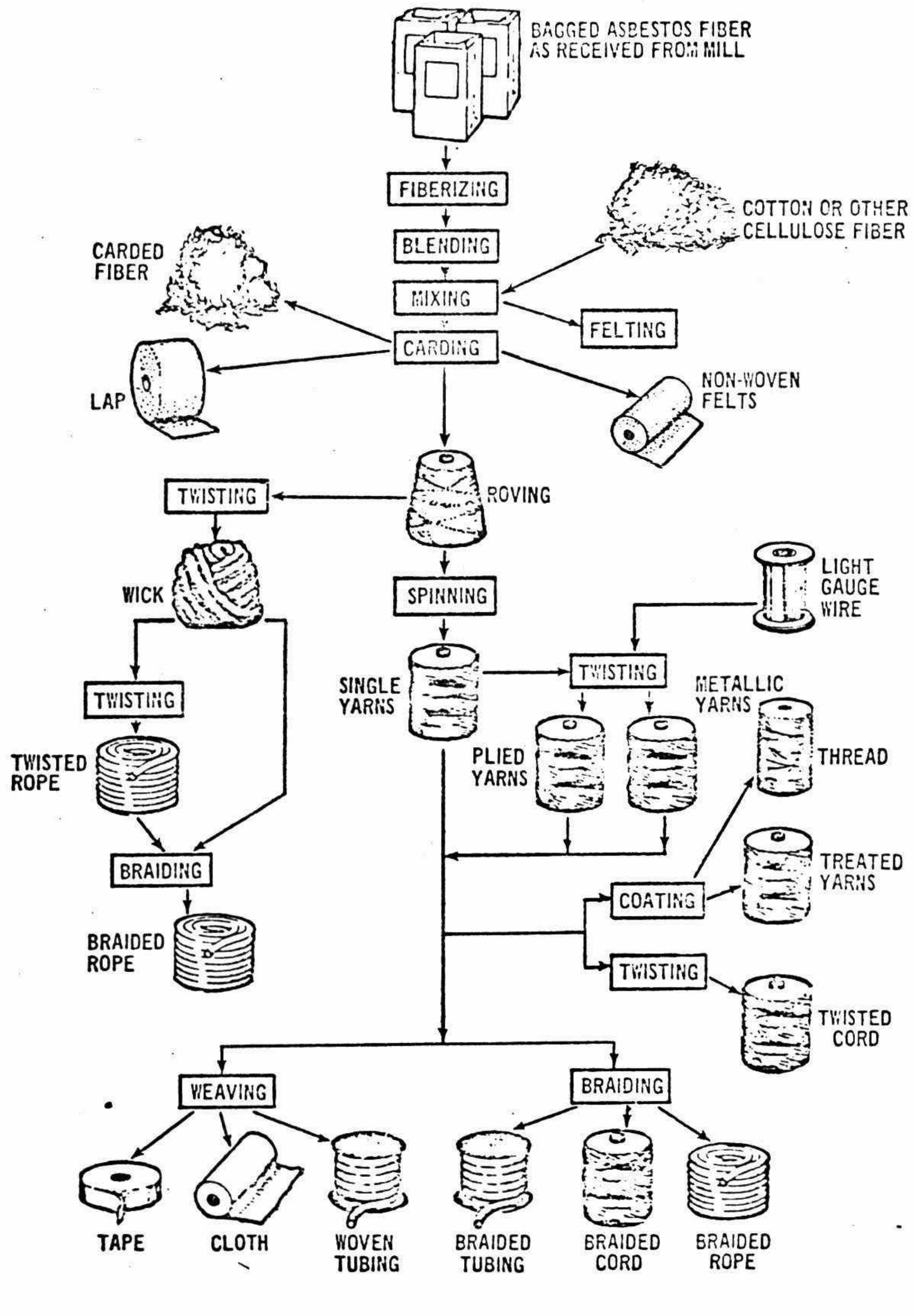


FIGURE 14. Manufacture of Asbestos Textile Products

EMISSION SOURCES -

Emissions can result from unloading, warehousing, transporting to bag opening areas, bag opening, and dumping of asbestos. The fluffing operation (used since fibres are compacted in travel) and the grading operation involve beating and combing processes that generate heavy dust concentrations. A considerably larger amount of dust results from fly willowing to recover fibres from wastes collected in cyclones.(56) Both the blending of various grades of asbestos fibres and the blending of asbestos with non-mineral fibres involve numerous handling and open transporting operations of the dry materials which, of course, have high emission potential. Also, the periodic cleaning of the different specific machines release large amounts of dust and fleece to the surroundings.(57)

The major source of asbestos emissions from twisting machines is the release of material from the yarn undergoing twisting as it is rapidly whipped through the air.(56) Emissions also result from the breakage of yarn and the subsequent rotation of the loose end by the spindle.

Weaving potentially generates more dust than any other textile operation, however, present control technology can reduce emissions to the extent that this process can be one of the cleanest of all the textile operations.(57) The principle emission source is the abrasion of yarn against the eyelets of heddle frames as the frames move up and down in the weaving process.(56)

CONTROL TECHNIQUES -

Dust capture hoods and fabric filtering devices again control dust in work areas and direct emissions into the atmosphere. Textile manufacturers have found it economical to control the temperature and humidity of the ventilating air in large work spaces. To minimize heating and cooling requirements, air removed from work spaces is sometimes recycled (rather than being exhausted into the atmosphere) after it has been sufficiently cleaned to meet occupational hygiene standards.(14) In contrasts to the practice of maintaining work spaces at slight negative pressures in order to alleviate emissions through windows, doors and structural leaks, the production areas of these mills are maintained at a slight positive pressure relative to the outside environment.(14) Plant operators consider this necessary to provide a temperature and humidity seal for the work areas. Accordingly, it is important to strictly control emissions at the source in order to prevent atmospheric discharge through structural openings at these facilities.

Most operations have controlled emissions but spinning frames are not frequently fitted with dust control devices, however, machines are now available that stop the rotation of the spindle when an end of yarn breaks.

EMISSION FACTORS -

In the United States, asbestos used in textiles during 1968 totaled 18,000 short tons.(13) An emission factor of 2 lb/ton was estimated by Davis and Associates which calculates to 18 short tons of asbestos being emitted into the atmosphere in 1968.(13)

James F. MacLaren Ltd. recognize the dry nature of the asbestos textile industry and they, following Davis, double their emission factor of 0.15 lb/ton.(15) Asbestos consumption of this industry totals 700 tons and emissions range to 0.11 tons for 1970. The E.P.A. feels that uncontrolled asbestos-textile operations can emit up to 40 lb/ton of asbestos processed, but with control equipment, this figure can be reduced to 2 lb/ton.(52)

05.06.06 ASBESTOS-ASPHALT PAVING COMPOUNDS -

When asbestos is added to asphalt paving compounds in the amount of 2% to 3% by weight, the quantity of asphalt in the mix can be increased by between 30% to 100% to yield a material containing 7% to 11% by weight asphalt.(14) The result is an improved pavement overlay with increased cohesion and abrasion resistance and decreased water permeability and material embrittlement.(14) This type of paving has been applied extensively in California, where it is estimated that more than 20% of the population resides in proximity to asbestos-asphalt paving. J.D. George, Chief Engineer of Research and Development, City of Toronto, reports that the Borough of North York converted to asbestos-asphalt paving of all their streets eight years ago.(58) In addition, the City resurfaces their freeways with asbestos asphalt. Figure 15. illustrates the mixing section of an asphalt manufacturing plant.

EMISSION SOURCES -

In the manufacture of paving compounds, the receiving and handling of the bags of asbestos fibres before mixing occurs are the potential sources of asbestos emissions.

CONTROL TECHNIQUES -

The enclosure of bag opening and emptying areas, storage bins, conveyor systems, and mixers can provide control of atmospheric emissions of asbestos. Also, the use of pulpable bags could reduce emissions. Exhaust fumes from these enclosures must be channeled through fabric filters.

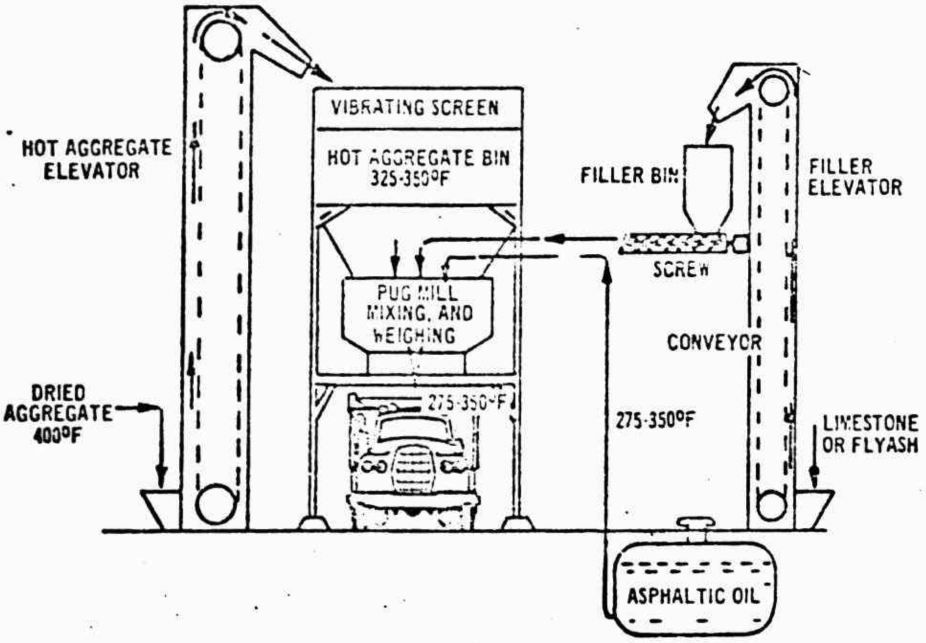


FIGURE 15. Mixing Section of Manufacturing Plant for Asphalt Paving

05.07 THE CONSUMPTION OF ASBESTOS PRODUCTS

05.07.01 SPRAYED ASBESTOS-CONTAINING INSULATION MATERIALS -

The spray application of asbestos-containing insulation materials is an extremely effective and economic means of fireproofing steel-reinforced structures and for acoustic and anti-condensation purposes.(3) Thermal insulation for high-temperature equipment such as chemical process vessels, steam turbine shells, furnace walls, and boiler walls is also installed by spraying.(13) Requirements for the two applications differ in that the layer of insulation must withstand thermal cycling in insulating high-temperature equipment as opposed to the design for a single thermal shock in the fireproofing of steel structures. Other asbestos-containing materials applied by spraying are specifically formulated to provide either ambient temperature thermal insulation or acoustical insulation.

The spraying technique has been developed to accommodate those situations in which the presence of irregular shapes and large areas would lead to difficulty and excessive cost in insulating by conventional block, mat, and hand troweling techniques. Some types of sprayed insulation materials can be tamped prior to drying to produce a decorative finish. A coat of sealer or paint can be applied either for decorative purposes or for improving resistance of the surface to the loss of material by abrasive action.(14)

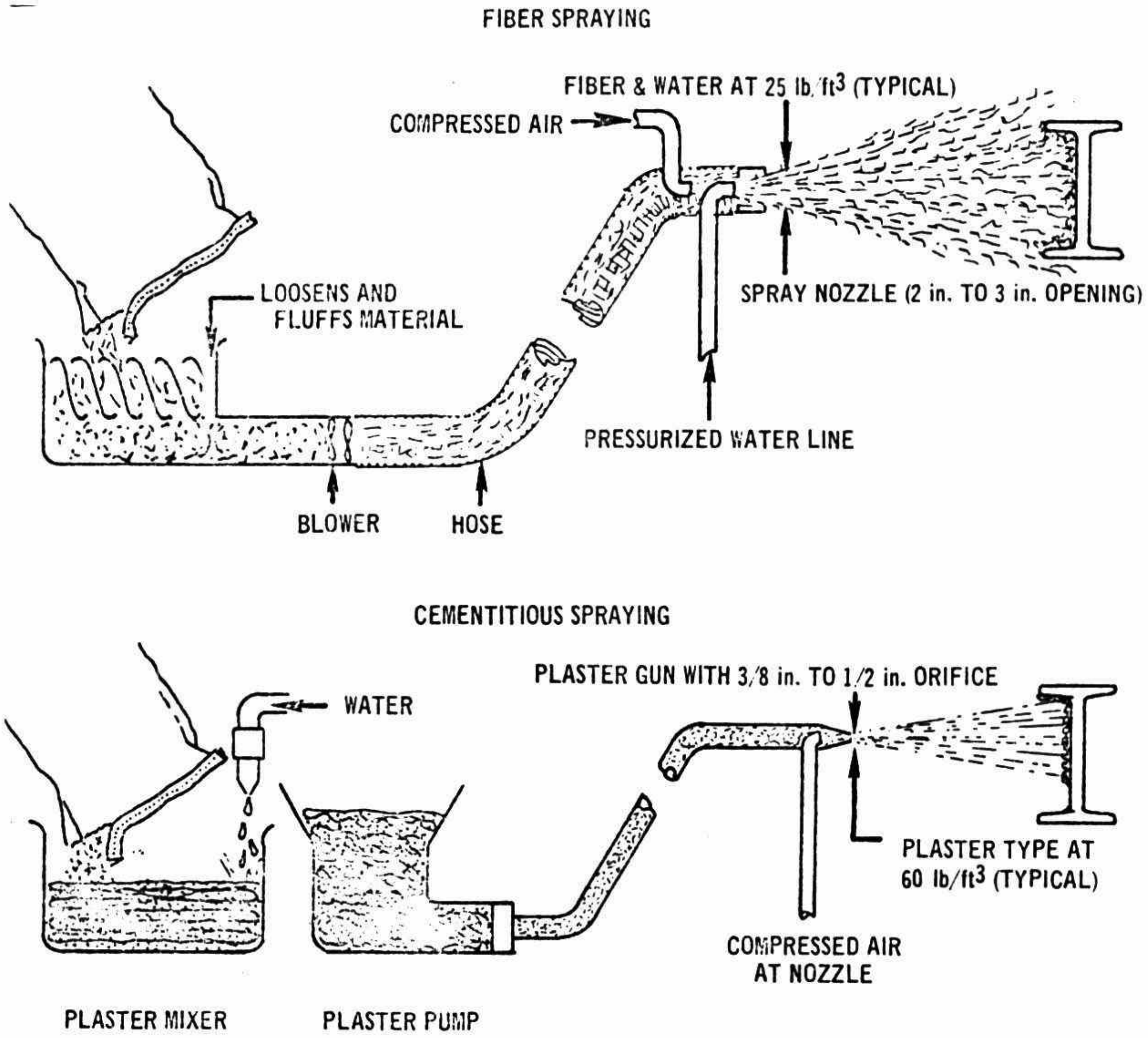
These spray-applied insulation materials contain asbestos fibres, a water-setting binder such as cement, and in some cases, other fibres such as glass wool or mineral wool. Amosite, crocidolite and chrysotile in amounts from 5% to 80% by weight are used.(14) Introduced in the 1930's, amosite was first used for ship insulation purposes while chrysotile began to be extensively used by the 1940's. Today, they are used in equal proportions while crocidolite is used only in trivial amounts in the United States.(20) Crocidolite was widely used in the British shipyards between 1940-1963 for environmental insulation (applied to deckheads and bulkheads) while chrysotile and amosite were used for pipe and machinery insulation.(47)

Two types of spraying processes in commercial use are shown in Figure 16. The spray nozzle is typically held 12" to 24" away from the surface to be insulated. Insulation is often applied in more than one layer and to a thickness of more than 2 inches.(14)

Asbestos-containing insulation is frequently sprayed in spaces directly open to the atmosphere. Asbestos spray fireproofing applied to buildings during construction, particularly high-rise structures in large metropolitan areas, is the most extensive single use of this type.(36)

EMISSION SOURCES -

The sight of flurries of asbestos fibres is commonplace on construction sites where sprayed insulation is used.(37) In some cases, these emissions are traceable to the incomplete wetting of dry insulating material either interior to, or slightly downstream from the outlet of the fibre spraying nozzle. Pre-damped material reduces emissions 100 fold.(3) Further, both the cementitious and fibre spraying techniques produce large quantities of wet insulation that does not adhere to the target surfaces. A portion of this wet material can be emitted directly into the atmosphere external to the work space, and large quantities settle onto surfaces of the work space beneath the sprayed area. The latter deposits can become secondary sources of asbestos emissions via disperal by vehicular and human traffic in the work area, particularly if the wet insulation dries before it is removed for waste disposal. As much as 25% of the material does not



FIBER SPRAYING

FIBER & WATER AT 25 lb/ft^3 (TYPICAL)
COMPRESSED AIR
LOOSENS AND FLUFFS MATERIAL
SPRAY NOZZLE (2 in. TO 3 in. OPENING)
PRESSURIZED WATER LINE
BLOWER
HOSE

CEMENTITIOUS SPRAYING

PLASTER GUN WITH 3/8 in. TO 1/2 in. ORIFICE
WATER
PLASTER TYPE AT 60 lb/ft^3 (TYPICAL)
COMPRESSED AIR AT NOZZLE
PLASTER MIXER
PLASTER PUMP

FIGURE 16. Spray Processes for Asbestos-Containing Insulation Materials

adhere to the steel and goes directly into the atmosphere.(36)

When asbestos-containing insulation is applied by spray techniques within structures that are essentially shielded from the external atmosphere, forced gas steams exhausted from the structures and incidental discharges of work-space ventilation air through windows and doors are potential sources of atmospheric asbestos emissions. In the course of transporting bags of dry spraying mixture to a job site and during the handling, stacking and storing of these in a work area, asbestos can be emitted to the work space from punctures in bags and from bag closures that are not dust tight. The manual opening of bags and the subsequent dumping of the contents into the hopper of a spray machine are potential emission sources that are similar to those encountered in the preliminary steps of manufacturing processes.

CONTROL TECHNIQUES -

Initial attempts to control excessive atmospheric asbestos emissions from the spray fireproofing of buildings under construction were directed toward the adoption of good housekeeping procedures at spraying sites and the containment of potential emissions within the structures.

The open perimeters of entire floors of new buildings should be shielded with tarpaulins and plastic sheets for the purpose of containing emissions from spray fireproofing. Recommended work practices include an initial cleaning of floor areas and the removal of portable objects (or the covering of such articles with dust-impervious tarpaulins or plastic sheets) to facilitate cleanup of spraying areas and thereby reduce potential emissions from this phase of waste disposal.(14)

The development of spray fireproofing and high temperature thermal insulating materials that contain little or no asbestos has been undertaken. One cementitious type of spray fireproofing compound containing no asbestos is now approved and in use.(14) Several asbestos-free spray fireproofing materials of the fibre type are also available and more substitute materials are under development. Asbestos-free materials will not require such stringent control methods that may otherwise result in excessive labour costs.

If sprayed asbestos insulation is employed within enclosed structures, potential asbestos emissions to the atmosphere can be controlled by sealing all openings through which contaminated air could be discharged to the exterior of the structure. In situations requiring ventilated spraying areas, fabric filters can clean the exhaust air prior to discharge to the atmosphere.

Insulation workers are the largest single occupational group to handle asbestos on the job but, sometimes bricklayers, carpenters, sheet metal workers and boiler makers apply insulation at various times because they do it without interrupting construction activities.(36) In this high risk operation, they often fail to take the precautions used by workers who handle asbestos on a daily basis. Applicators and construction workers nearby can inhale up to 50 million fibres in an 8 hour day.(36) Licensing of workers who install insulation, much like the licensing of plumbers and electricians, has been suggested as a safeguard to insure that asbestos handlers are both informed and equipped to work safely.

The installation of sprayed asbestos has recently been recognized by environmental authorities as one of the most flagrant violators of the ambient urban atmosphere in terms of asbestos emissions. In February, 1972, New York City was the first to ban the use of asbestos spray insulation and by December of 1973, the Environmental Protection Agency followed New York, Boston, Philadelphia, and the State of Illinois, and took the first steps to ban outright the spraying of asbestos on the construction site.(37)

EMISSION FACTORS -

Asbestos emissions to the atmosphere, due to the use of spray-on fireproofing during 1968, (by 1970, well over 1/2 of all multi-storey buildings in the U.S. used asbestos spray insulation)(15) are estimated by Davis and Associates at 15 short tons based on an emission factor of 10 pounds per ton of asbestos applied.(13) Since the manufacture of insulation is considered by James F. MacLaren Ltd. to be similar to the manufacture of textiles, a 0.3 lb/ton figure was used as an emission factor.(15) They calculated 2.18 tons of asbestos emitted into the Canadian atmosphere in 1970.(15) The E.P.A. estimates an emission factor of 10 lb/ton for any controlled steel fireproofing operation as presented in Table 11.

05.07.02 CONSTRUCTION/DEMOLITION -

Two-thirds of all the asbestos consumed in the U.S. is used for construction products.(31) The electrician strips asbestos insulated wire.(1)(15) The carpenter saws asbestos board and often pounds asbestos insulated furnace ducts to make them fit.(13)(15) Plumbers install asbestos valve packings and pipe coverings and cut asbestos cement pipe.(15) As a result, the foreman, carpenter, painter, plumber and even the new occupants of the residence all breath this dust.(1) As well as subjecting construction workers to asbestos fibres, construction sites are also a source of ambient air pollution. The nature of this source makes control difficult.

Crocidolite asbestos is generally recognized as the most toxic variety and its use has been recommended to be kept to a minimum. In the United Kingdom, its use has been banned in any material manufactured for the building or construction industry.(3) Blue asbestos presents a particular problem in the demolition of buildings requiring stringent precautions.(30) Care should be taken to discover if it is present.

CONTROL TECHNIQUES -

Control techniques, in addition to good housekeeping, include power tools that are fitted with shrouds or nozzles used with standard self-contained portable exhaust ventilation units.(3) Dust collecting bags must be easily removable and disposable.

The most frequently applied asbestos emission control technique for demolition operations is the thorough wetting of the surface and, where possible, water soaking of asbestos-containing materials prior to stripping of the materials or breakup of an entire structure. The use of additional quantities of water together with enclosed conveying chutes can reduce emissions during the loading of demolition wastes into transportation vehicles. When ambient temperatures are below freezing, however, the opportunities for dust suppression by wetting of wastes are limited.

The stripping of asbestos-containing materials, particularly those which are friable, prior to the breakup of a structure is a more direct method of controlling asbestos emissions during demolition than is the application of dust control measures during the fragmentation of an entire building simultaneously with the asbestos wastes.

Canadian wrecking companies indicate that very little asbestos insulation is encountered during the demolition of old buildings.(15) This seems reasonable since asbestos sprays have only been used since the early 1950's in Canada.(15) Generally, though, it is recommended that asbestos material in the building be removed manually with as little breakage as possible before demolition begins. Canadian companies do this anyway, recovering it for resale.(15)

EMISSION FACTORS -

Emissions are difficult to assess. Although the lack of controls would tend to give a relatively high emission factor, the small amounts of dust involved relative to the manufacturing and mining processes would tend to decrease the emission factor. Lacking definitive information, James F. MacLaren Ltd. assumed approximately 20% of asbestos consumption in Canada (about 12,000 tons in 1970) enters the construction industry in a form that could produce emissions.(15) Using an emission factor of 0.15 lb/ton, 0.9 tons of asbestos were emitted in 1970.(15) Davis and Associates estimate 61 short tons for the U.S. in 1968.(13) Table 11. specifies the E.P.A.'s estimated emission factor.(52)

TABLE 11.

EMISSION FACTORS FOR CONSUMPTIVE USES OF ASBESTOS[a]

Source[b]	Emission Factor, lb/ton of asbestos applied
Brake linings	10[c]
Steel fireproofing, controlled	10
Insulating cement, controlled	25
Construction industry	25

[a] The emission factors are based on engineering estimates and no source sampling. These factors cannot be used to quantify asbestos emissions.

[b] Uncontrolled unless otherwise specified.

[c] A factor of 0.0005 pound per 10^3 vehicle miles can also be used.

Source: Emission Factors for Trace Substances,
U.S. Environmental Protection Agency,
EPA-450/ 2-73-001

(52) in the Bibliography.

05.08 WASTE DISPOSAL

The recovery of scrap is an important factor in some industries, but asbestos, once used, is rarely recovered for reuse. In most products, asbestos is combined with other materials in such a manner that it is difficult to separate into a useable form. Most of the discarded products that contain asbestos become part of the solid waste. Incineration can release some asbestos fibres.

The exposure in open-dumping sites of such diverse wastes as asbestos mine overburden, oversized masses of screened asbestos ore, asbestos mill tailings, emptied asbestos shipping bags, and the consolidated overspray of asbestos-containing insulation provides an opportunity for the entrainment and widespread dispersion of asbestos fibres into the atmosphere. Atmospheric emissions can also result from the open disposal of the material collected by fibric filter devices, from the open disposal of scrap pieces of insulating materials and asbestos-cement products that carry surface deposits of asbestos dust produced by fabrication and field installation operations, from the weathering in open dumps of even those materials in which asbestos is originally present in a bound condition, and from the disposal of emptied shipping containers for asbestos.

The properly managed disposal of emptied bags in a dump is thought to generate less emissions than the incineration of such bags; however, the degree of thermal degradation of the asbestos during incineration has not been fully evaluated.(14)

Potential emissions associated with the removal of dry, asbestos-containing materials collected by gas-cleaning devices can be controlled by providing a dust-tight sealing arrangement between the collector hopper and the disposal bag or bin.(14) When wastes are collected by smaller, portable vacuum cleaning equipment, single-service bags can be employed to eliminate the necessity for transferring the waste to an intermediate container prior to disposal. Asbestos-containing sludge from wet collectors should be drained into moisture-proof vats suitable for transporting the waste to a dumping site.

As asbestos-bearing wastes that have been collected and consolidated undergo disposal, emphasis should be placed upon emission suppression during transportation, dumping, and repose in the dump.(14) Wastes that are otherwise uncontained are preferably placed into dust-tight bags or other dust-tight containers for transit to the disposal location.

05.09 OCCUPATIONAL CONTROL TECHNIQUES

References(1)(6)(7)(17)(21)(24)(29)(34)(37)(48)

The control techniques for asbestos operations, in principle, are widely applicable throughout the industry. These principles are discussed below.

A - EXHAUST VENTILATION

Asbestos fibres should be captured before it can disseminate and contaminate the immediate and adjoining work areas. Requirements are established by several agencies for the proper ventilation design, fibre capture and carrying velocities and enclosed baghouse collecting systems.

B - ENCLOSURE AND ISOLATION

This method of control is most useful when used with batch making and the handling of loose asbestos. It is also very important in the handling of solid waste. Enclosure and isolation of the operation prevents the dissemination of the fibre into other areas where workers not related to the operation may be unsuspectedly exposed.

C - WET METHODS

The wetting of asbestos should be considered where feasible as it is an effective yet inexpensive method of dust control. It can be used in mixing, drilling, sawing, sanding and cleanup operations, but special precautions must be taken so as not to let the sludge dry up.

D - GOOD HOUSEKEEPING AND MAINTENANCE

This is an essential operation since, without such a program, a hazard may exist in an otherwise well constructed and operated plant. Some elements of good housekeeping are:

(1) repairing leaks and improperly operated equipment

(2) immediate cleaning up of spills

(3) routine cleaning of all in-plant areas including floors, structural members, and equipment using vacuum cleaning and water

(4) cleaning of areas outside the plant and keeping dust suppressed by use of water.

E - WORKER EDUCATION

This is often neglected as an effective control method. The worker knowledgeable of the hazards associated with the job is more apt to protect himself. Workers should be instructed in the proper use of equipment and in good practices in the handling of the material with which they are working.

F - GOOD WORK AND SANITATION HABITS

Work clothing can be contaminated and provide a continuing source of exposure during the work shift and after. Excessive asbestos dust on the skin for long periods can cause skin irritation and penetration by the fibre. Cleanliness and disposable protective clothing should be used as the situation demands.

G - PERSONAL RESPIRATORY PROTECTION

This is an effective way of preventing exposure to dust where heavy intermittent levels are encountered and other means of protection are not feasible (ie., equipment breakdowns, maintenance and repair operations).

H - SCHEDULING OF ASBESTOS WORK

This method, especially valuable in insulation work on con-

TABLE 12.

	PROCESS	APPLICATION	SUBSTITUTE
1.	woven asbestos	heat-resistant clothing	wool clothing, glass wool clothing, for gloves during glass blowing for example, still not in solution
		packing	aluminum silicate
2.	bonded with rubber, synthetic resin or bitumen	packing	aluminum silicate
		floor covering,	no substitute
		paste (roof),	glass fibre
		brake linings	substitute already used
		asbestos cement sheets	for wall lining, possibly gypsum plates; no other substitute
4.	bonded with lime	thermic insulation; fire-proof walls	possibly gypsum plates
5.	loose asbestos	thermic insulation	the insulation materials listed in text
6.	asbestos paper	placking plates;	aluminum silicate
		supports for floor covering	no substitute yet; perhaps glass gauge.
7.	asbestos mixed with cellulose	filters	glass wool
		asbestos boards	aluminum silicate

struction sites, is used to minimize the asbestos exposure to the surrounding workers. It is also valuable in special circumstances like ship construction and repairs where confined spaces and restricted entries make dust control difficult and the presence of many other workers nearby make asbestos work extremely hazardous.

I - SUBSTITUTION OF ASBESTOS

The most effective means to prevent asbestos emissions into the atmosphere is to substitute other materials for it. There is no single substituting agent because there are too great differences between the types of processing and application. Available means could substitute asbestos in specific areas but, they fail in other applications. Due to their specific properties, these substitutes are mostly cheaper and better in their field of application than asbestos and its products.

Table 12. shows that in many instances aluminum silicate can replace asbestos. In individual cases, good results have been obtained. In the glass industry where the products are wrapped with asbestos paper to prevent sheets sticking to each other, aluminum silicate was used as a substitute with success. Its high price is an obstacle in the way of wider application. It should also be pointed out that the use of substitutes for asbestos is often much cheaper, and sometimes offer weight advantages as well. However, the selection of substitutes is not easy; for each product, it is necessary to conduct separate research since the approach of the manufacturing process is sometimes entirely different.

As is known, a great deal of asbestos is being utilized in the insulation product industry. In this industry, many good substitutes are available. Their field of application depends on the operational temperature and can be subdivided into 4 sectors:

a. Very low temperatures - 250° C to 0° C in refrigerating technology

b. Low temperatures - 0° to 250° C cold water, warm water and low-pressure steam

c. High temperatures, up to +550°C, superheated steam station and steamships

d. Very high temperatures, up to +1,300°C

Suitable Substitutes:

a. For very low temperatures -

1. polystyrene foam, -40° to +50°C
2. polyurethane foam, soft, -40° to +110°C
3. polyurethane foam, hard, -200° to +110°C
4. cork, -250° to +130°C
5. glass foam, -260°C to +430°C

b. For low temperatures -

1. polythyrene foam, -40°C to +50°C
2. polyurethane foam, soft, -40°C to +110°C
3. polyurethane foam, hard, -200°C to +110°C
4. cork, -250°C to +130°C
5. glass foam, -260°C to 430°C
6. flax fibre, up to +100°C
7. glass wool, up to +550°C
8. mineral wool, up to +750°C

c. For high temperatures -

7. glass wool, up to +550°C
8. mineral wool, up to +750°C
9. expanded rock, up to +1,100°C

D. For very high temperatures -

9. expanded rock, up to +1,100°C
10. aluminum silicate, up to +1,260°C

Properties of the above listed insulation materials:

1. polystyrene foam -
    a. synthetic foam with closed cells
    b. temperature range -40°C to +50°C
    c. thermic conductivity coefficient at 1° = 0.030 kcal/mh°C
    d. moisture adsorption is low, 4-6 vol. %
    e. processing: sawing and cutting
    f. resistant to putrefactive bacteria
    g. supplied in plates
    h. flammable
    i. weight 15 kg/m^3

2. polyurethane foam (soft) -

a. synthetic foam with closed cells
b. temperature range, -40°C to +110°C
c. thermic conductivity coefficient at 0°C = 0.028 kcal/mh°C
d. moisture adsorption is low
e. processing: nipping off and cutting
f. resistance to putrefactive bacteria
g. supplied in sheets
h. fire extinguishing
i. weight 47 kg/m^3

3. polyurethane foam (hard) -

a. hard synthetic foam with closed cells
b. temperature range, 200°C to +110°C
c. thermic conductivity coefficient at 0°C = 0.020 kcal/mh°C
d. moisture adsorption is low, 0.05 vol. %
e. processing: cutting and sawing; as two liquid components to be sprayed or poured into cavities
f. resistance to putrefactive bacteria
g. supplied in sheets, shaped parts, as two liquid components
h. fire extinguishing
i. weight 36 kg/m^3

4. Cork -

a. expanded cork grains
b. temperature range, -250°C to +130°C
c. thermic conductivity coefficient at 0°C = 0.030 kcal/mh^3
d. low moisture adsorption - 2 1/2 vol. %
e. processing: cutting and sawing
f. resistance to putrefactive bacteria
g. supplied in sheets, shaped parts and loose grains
h. flammable
i. weight 110 to 180 kg/m^3

5. Glass Foam -

a. 99% blown glass
b. temperature range, -260°C to +430°C
c. thermic conductivity coefficient at 0°C = 0.046 kcal/mh°C
d. low moisture adsorption: 0.2 vol. %
e. treatment - cutting and sawing
f. resistance to putrefactive bacteria and all acids except hydrofluoric acid
g. supplied in sheets and shaped parts
h. inflammable
i. weight 144 kg/m^3

6. Flax Fibre -

a. pressed and fermented flax
b. temperature range 0° to 100°C
c. thermic conductivity coefficient at 0°C = 0.35 kcal/mh°C
d. humidity absorption
e. processing, cutting, sawing
f. reasonable resistance to all kinds of factors
g. supplied in sheets and shaped parts
h. flammable
i. weight 190 kg/m^3

7. Glass Wool -

a. molten glass spun to thin fibres
b. temperature range up to +550°C
c. thermic conductivity coefficient at 250°C = 0.065 kcal/mh°C
d. little humidity adsorption: 0.06 vol. %
e. processing - stopping and filling to wool, cutting to sheets
f. resistance to putrefactive bacteria, chemically neutral
g. supplied as: loose wool
sheets bonded with resin
covers with metal netting
cords
yarn
texture covers
h. not flammable
i. weight: contingent upon design, from 8 kg/m^3 to 160 kg/m^3

8. Mineral Wool -

a. made from molten silicates spun to thin fibres
b. temperature range up to +750°C
c. thermic conductivity coefficient at 250°C = 0.8 kcal/mh^3
d. little humidity adsorption: 0.14 vol. %
e. processing: stopping, filling for loose wool,
cutting, nipping off, for sheets
f. resistance to putrefactive bacteria and chemically neutral
g. supplied as: loose wool
sheets bonded with plastic material
covers with gauze
h. not flammable
i. weight 20 kg/m^3 to 160 kg/m^3

9. Expanded Rock -

a. made from mineral rock such as mica.
The rock is heated to 1,000°C, whereby grains with air cells develop.

b. temperature range to 1,000°C
c. thermic conductivity coefficient at 250°C = 0.039 kcal/mh°C
d. humidity adsorption: takes up a great deal of moisture
e. processing: spill into hollow cavities for loose grains;
cutting and sawing for sheets and shaped parts.
f. resistance to putrefactive bacteria
g. supplied as: loose grains,
sheets and shaped parts.
h. not flammable
i. weight 100 kg/m^3

10. Aluminum Silicate -

a. is a ceramic fibre which can be supplied in many different forms
b. temperature range to 1,260°C
c. thermic conductivity coefficient at 700°C = 0.150 kcal/mh°C
d. little humidity adsorption, comparable with glass or mineral wool
e. processing: stuffing and filling for loose wool,
cutting and nipping off for covers and felt.
f. resistance to putrefactive bacteria
g. supplied as: loose wool
felt
board
paper
cord
shaped parts
h. not flammable
i. weight 65 kg/m^3

05.10 ASBESTOS EMISSION CONTROL TECHNIQUES

There are three gas-cleaning devices (fabric filters, dry centrifugal collectors and wet collectors) which are usually applied to the control of asbestos emissions. After careful study, there is no doubt that fabric filters, or "baghouses", currently represent the best available technology, and are the most efficient gas-cleaning devices available (see Table 13).(63)

A fabric filter is a device used for freeing process gases (or liquids) from suspended impurities. Particulates as small as 0.5 um in diameter can be collected with high efficiency, and even those as small as 0.1 um can be removed at somewhat reduced efficiency after a dust layer has been deposited on the fabric. Direct interception and impaction collect particles above 1 um, diffusion collects particles less than 0.1 - 0.2 um. (60)(64) Particles greater than 0.01 um are affected by electrostatic attraction.(60)

The type of fabric chosen for the filter is important to collection efficiency and ease of cleaning. The filter material most commonly used for asbestos is cotton sateen except for the control of ore dryer emissions; in this case, cotton is unsuitable for the high-temperature effluent gases of the dryer.(14) The useful lifetime of cotton bags is reported as 6 to 7 years.(61) Wool felts have also been used for several years, but synthetic felts have only recently gained acceptance by the asbestos industry. Felted fabrics are commonly associated with higher air-to-cloth ratios (4-1 and 12-1) and are not normally used for the collection of extremely fine metallurgical fume because the embediment of the fine particles in the felt makes cleaning very difficult.(63) But, because of the finer fibres in needle felt materials, felted fabrics can result in the better collection of fine particulate.(60)

TABLE 13.(14)

AIR POLLUTION CONTROL EQUIPMENT COLLECTION EFFICIENCIES

Equipment Type	Typical Efficiency Ranges (on total weight basis), percent
Low-energy mechanical	50 to 70
High-energy mechanical	70 to 90
Low-energy wet collector	50 to 75
Medium-energy wet collector	75 to 90
High-energy wet collector	90 to 99.5+
Fabric filter	95 to 99.9

Table 14. lists the various applications of fabric filters. The nature of some of the processes described requires that the collectors operate continuously, whereas, in other instances, the filters can be cleaned periodically when a process is shut down. Cleaning cycles vary from 1 minute of shaking during each 30 minutes of operation in a mill to one cleaning every 2 hours of operation at the finishing end of an asbestos-cement pipe manufacturing plant.(61) Woven bags are usually cleaned by the action of a mechanical shaking device. Felted fabrics are normally limited to cleaning by high pressure reverse jet or jet pulse at frequent cleaning intervals.(63)

Variations of bag length and diameter between collectors result from space and efficiency compromises among small-diameter bags to minimize required floor area, larger-diameter bags to reduce the likelihood of longer fibres plugging the bags and longer bags to fit a filter into smaller floor areas.(14)

The collection efficiency of a baghouse is dependant on several factors. In an asbestos mill, collection efficiencies greater than 99.99% have been exhibited by fabric filters receiving a dust concentration of approximately 1 gram per standard cubic foot.(61) The consistent attainment of an exit fibre concentration of 0.5 fibre per cubic centimeter is possible.(14) Tests have shown that exit dust concentrations observed immediately after initiating air flow through a cleaned cotton sateen bag are considerably larger than those for normal operation (lower values reached within 3 minutes).(14)

The mechanism of impingement of larger particles on filter material has a very high efficiency rate which increases as the air-to-cloth ratio increases.(64) On the other hand, if the efficiency of the diffusion process, which collects the sub-micron particles, is to be high,

TABLE 14.(14)

APPLICATIONS OF FABRIC FILTERS

Application	Operation	Cloth	Bag Length in.	Bag Diameter in.	Filtering Velocity, ft./min.	Expected Pressure Drop, in. H_2O
Asbestos milling	Continuous	Cotton sateen	168	5	2.5 to 3.0	2.5 to 4.0
Asbestos ore dryers	Continuous	Orlon	168	5	2.5	1.5 to 2.0
Asbestos-cement raw material handling	Continuous	Cotton sateen	126	5	2.5	3.0
Asbestos-cement finishing machines	Intermittent	Cotton sateen	168	5	2.0	1.5 to 2.0
Textile carding	Intermittent	Cotton sateen	126 to 168	8	5	1.5 to 2.0

the velocity of approach should be low.(64) This leads to a zone of operating conditions for any filter where the overall efficiency will be low. From Table 14., short thin fibres are expected from the asbestos-cement finishing machines, therefore requiring a lower filtering velocity than textile carding where much longer fibres are expected.

Filter fibre size and weaves are also important. As a general rule, a finer filament size (diameter) is preferable. The advantages are higher efficiency (the smaller the fibre the smaller the particles collected, ie. diffusion improved), and the lower pressure drop (high surface area and greater flexability).(60)(63)

Two special properties of asbestos must be considered in regard to the cleaning of asbestos-laden air; electrostatic charge and aerodynamic behaviour in relation to filter face orientation. Asbestos fibres can carry a large natural electrostatic charge(68) whereas the fabric of the baghouse, being a poor conductor, can easily be charged by the filtering action.(60) If the particles and fabric have opposing charges or similar charges with a sufficient difference in voltage, an attraction exists (which could improve baghouse performance). Considerable research is needed into this electrostatic phenomena.

The second point to be given special attention is the asbestos fibre's orientation to the filter face. Do asbestos fibres follow the Brownian principle in exhaust gas air streams or do they aligne aerodynamically? Since the diameter of the asbestos fibres is measured in angstroms, but the length in microns, collection efficiency would be greatly enhanced if the asbestos material could be impacted lengthwise. Further research is needed in this area.

05.10.01 COST OF CONTROL MEASURES

The expenditures for installation and operation of any air pollution control system can be categorized as capital investment, maintenance and operating costs, and capital charges. Within these categories, it is convenient to identify several types of costs:

1. Capital Investment:
   - Control hardware
   - Auxiliary equipment
   - Installation
   - Engineering studies
   - Land
   - Operating supply inventory
   - Startup
   - Structure modification
2. Maintenance and Operation:
   - Labour
   - Supplies and materials
   - Utilities
   - Treatment and disposal of collected material
3. Capital Charges:
   - Insurance
   - Interest
   - Taxes

Table 15. identifies the conditions affecting the purchase and installation costs. Although the total installed costs of baghouses vary widely (examples in Source (14) show $11,900 to $295,000), the economic impact can be handled by most large companies. Smaller uncontrolled companies may encounter economic difficulties.

TABLE 15.

CONDITIONS AFFECTING PURCHASE AND INSTALLATION COSTS

Cost category	Low to typical costs	High to extremely high costs
Equipment transportation	Minimum distance; simple loading and unloading procedures	Extensive distance; complex procedure for loading and unloading
Plant age	Hardware designed into new plant as an integral part of process	Hardware installed into confines of old plant requiring structural or process modification or alteration
Available space	Vacant area for location of control system	Little vacant space; extensive steel support construction and site preparation required
Instrumentation	Little required	Complex instrumentation required to assure reliability of control or constant monitoring of gas stream
Guarantee on performance	None required	Guaranteed high collector efficiency to meet stringent control requirements
Degree of engineering design	Standard "package type" control system	Control system requiring extensive integration with process, insulation to correct temperature and moisture problem, noise abatement
Degree of assembly	Control hardware shipped completely assembled	Control hardware to be assembled and erected in the field
Utilities	Electricity, water, waste disposal facilities readily available	Electrical and waste treatment facilities must be expanded; water supply must be developed or expanded
Collected waste material handling	No special treatment facilities or handling required	Special treatment facilities and/or handling required
Labor	Low wages in geographical area	Overtime and/or high-wage geographical area
Auxiliary equipment	Simple draft fan; minimal ductwork	Extensive cooling equipment ductwork, large motors
Corrosiveness	Noncorrosive gas	Acidic emissions requiring high alloy accessory equipment using special handling and construction techniques

INSTALLED COST EXPRESSED AS A PERCENTAGE OF PURCHASE COST FOR TYPES OF CONTROL DEVICES

	Cost range, percent			
Generic type	Low	Typical	High	Extremely high
Fabric filters	150	180	200	500

Source: (14) in the References.

Figure 18. shows the fabric filter and fan floor of the Jeffrey Mine in Asbestos, Quebec. Figure 19. is a plan of the layout of the Reeves Mine fabric filter and air system near Timmins, Ontario.

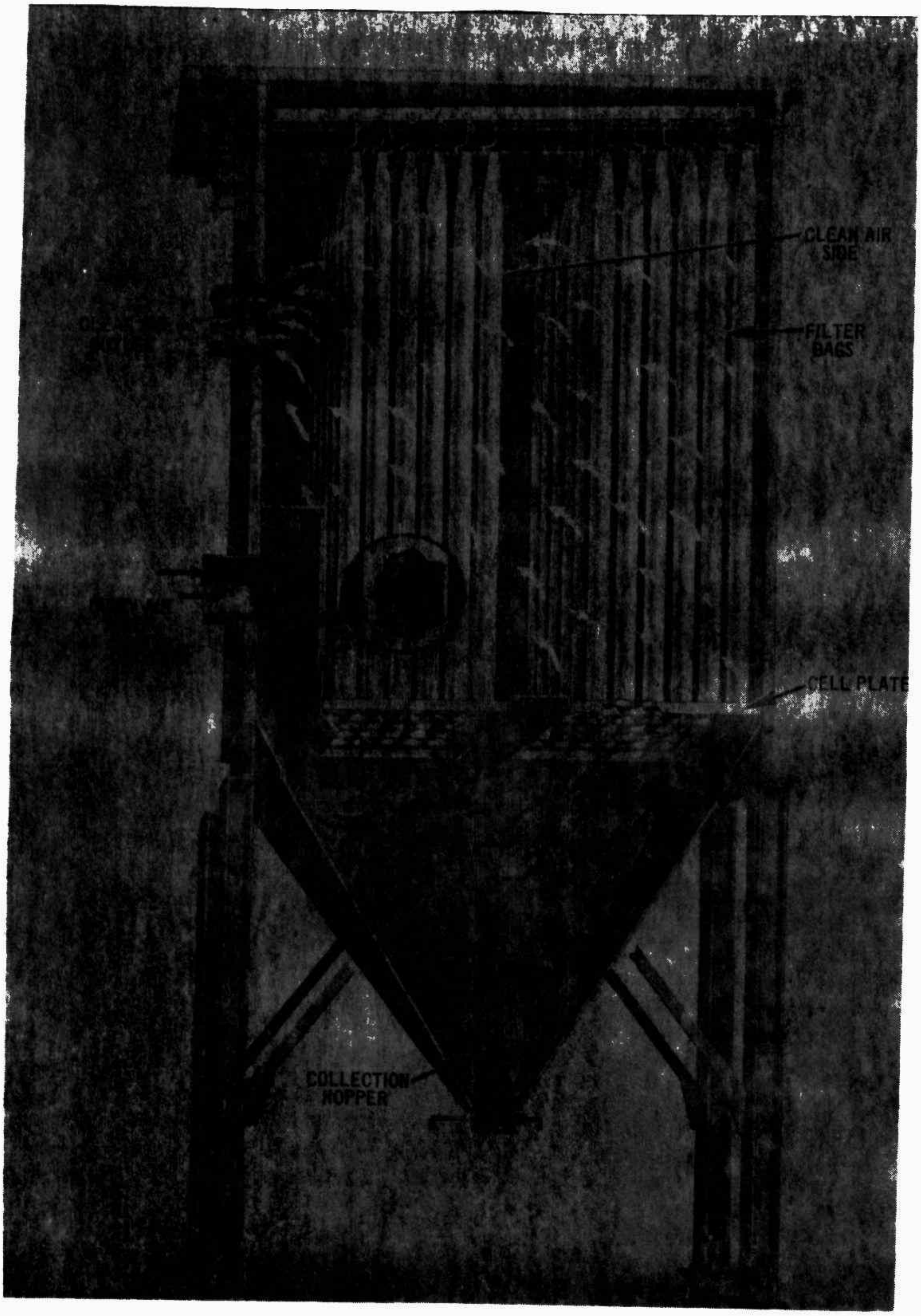


FIGURE 17.(14) Sectional View of a Baghouse

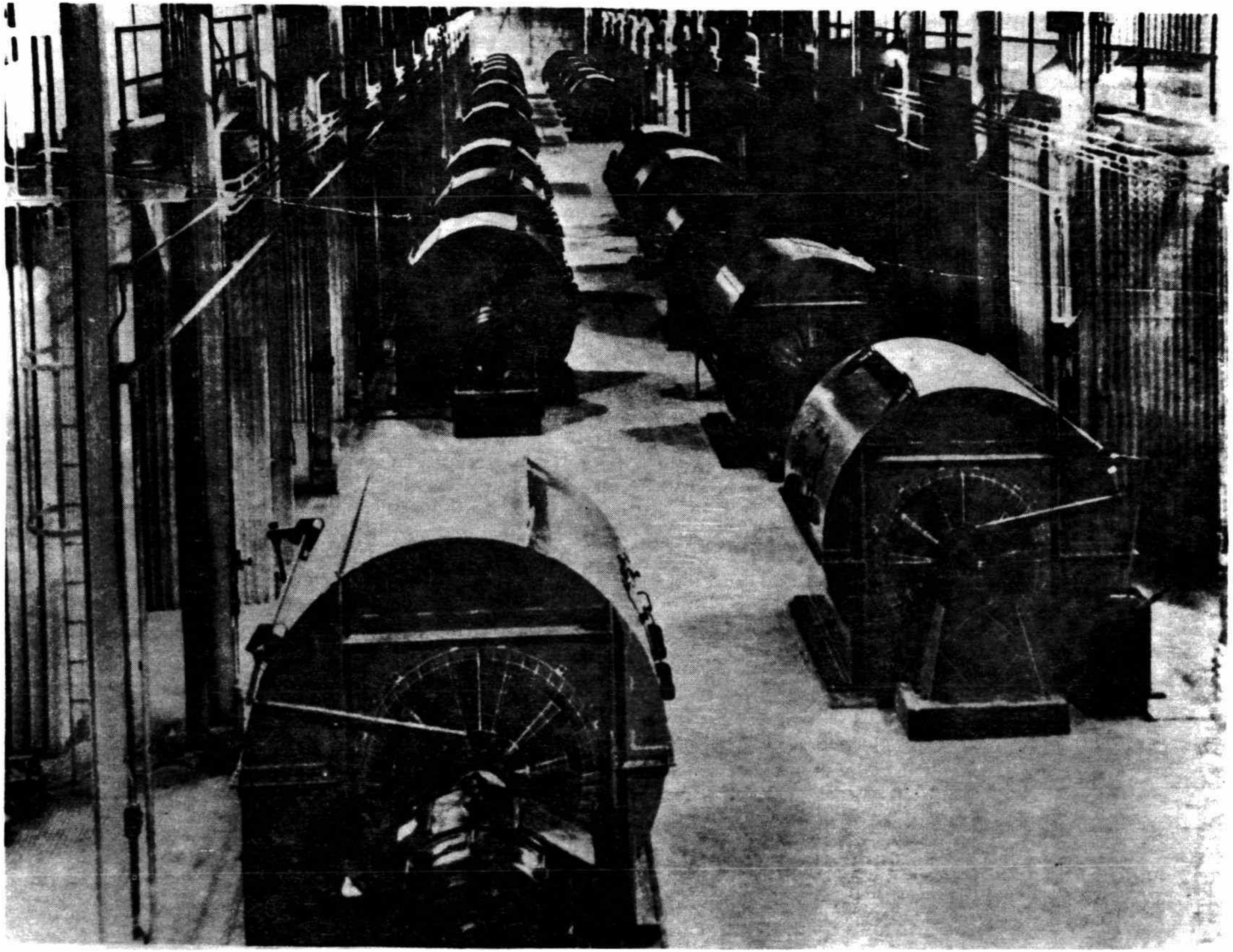
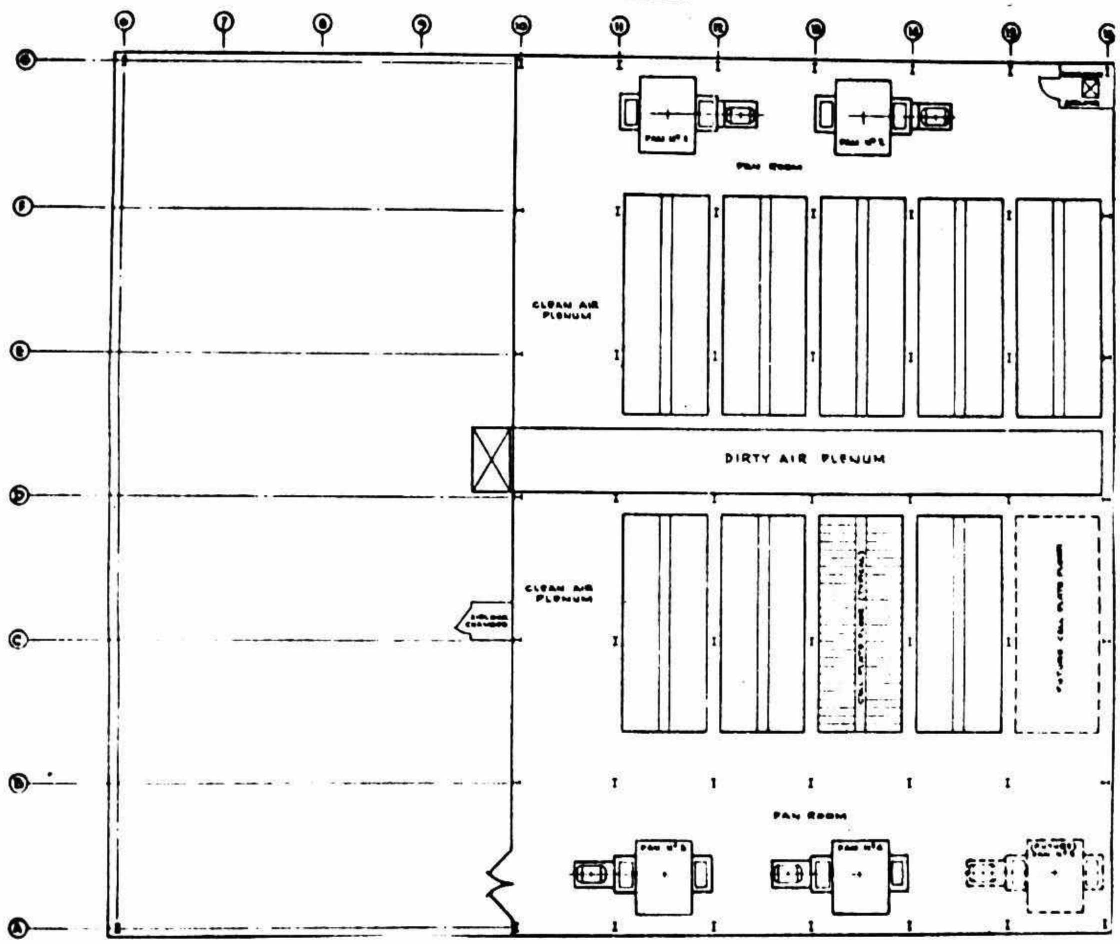
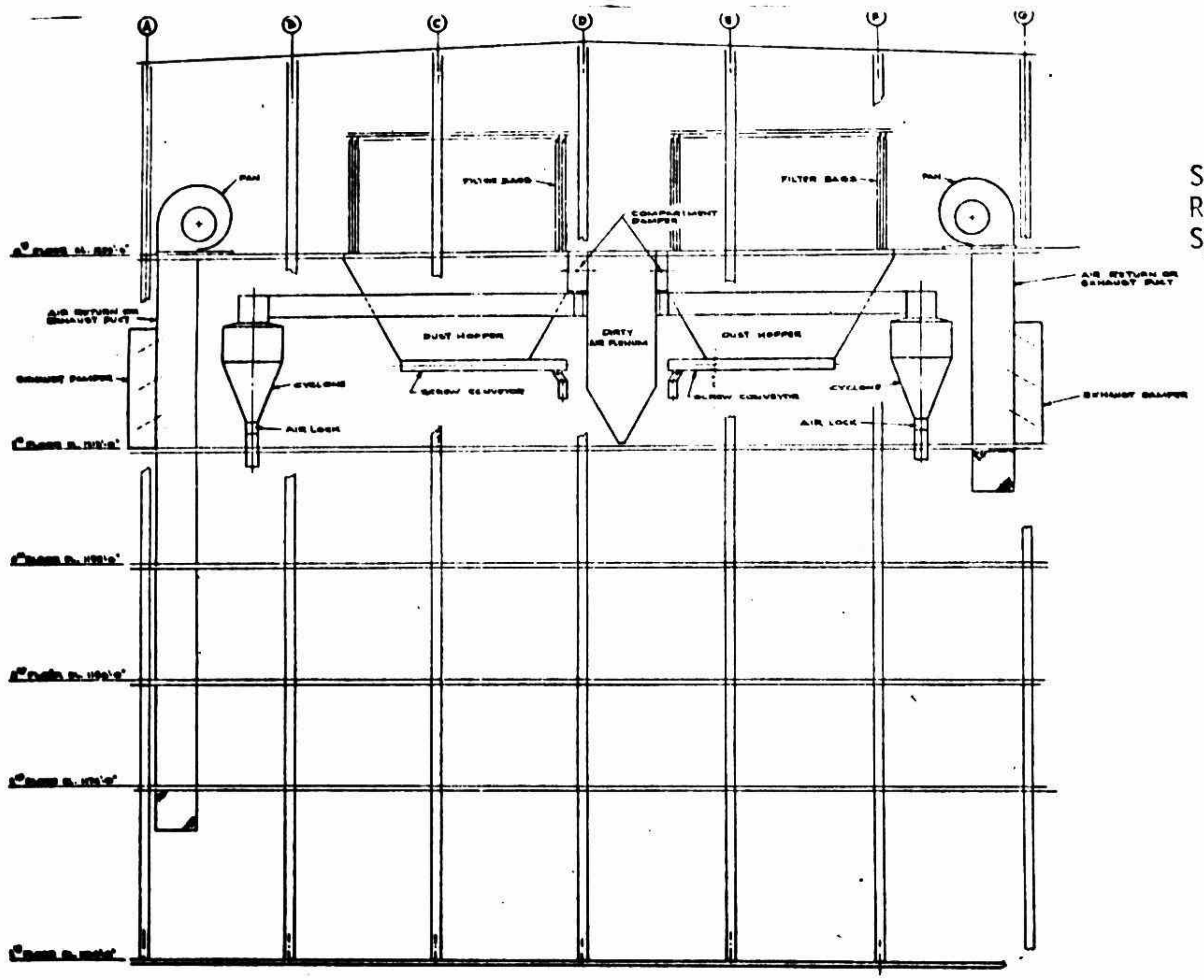


FIGURE 18. Baghouse Application in Jeffrey Mine, Asbestos, Quebec. Reference (61)

FIGURE 19.(61)



Layout of Reeves Mine Fabric Filter



Section Through Reeves Mine Air System

05.11 CONCLUSIONS

The types of asbestos exposure are so varied and numerous, it is almost certain that everyone in North America has come into contact with it in one way or another. Since so little is really known about harmful concentration levels and dose/response relationships, the sources and methods of control, therefore, become very important. Although, as will be seen later, the levels of asbestos generally found in urban air are not considered to be hazardous; it is felt by many authorities that any increase above present concentrations would be unfavourable. For these reasons, recommended control would include only the best available technology. This, in essence, would require fabric filter devices used to clean air exhausted to the atmosphere. Considering the varied nature of the sources, the application of baghouses would not be feasible all the time (ie., the diversity of sources in the mining/milling operation). In this regard, a code of practise for asbestos operations should also be included. An extensive code of practise covering mining, milling, transporting, handling (loading and unloading), construction, demolition and other miscellaneous uses of asbestos will be required.

Asbestos manufacturing in Ontario is not a major industry as 94.5% of the total Canadian production of the fibre is exported.(15) Canada remains the largest exporter of the mineral.(70) Only 3% is used for domestic consumption but, of the goods produced, 90% stay within the country.(15) Consequently, except for a few larger plants, the asbestos operations tend to be small operations in Ontario. Asbestos, in this situation, is usually emitted from roof vents or short stacks with little or no dispersion. The consequent release of pollutants at a relatively low height is compounded by aerodynamic downwash effects that often influence these sources.

Ontario.

It is not the purpose of any ambient air standards or objectives to force small marginal production operations out of business. However, strict regulation of asbestos concentrations using best available technology is not unfeasible. Small plants tend to have bad land-use patterns so dispersion of their pollutants should not be allowed but, flexibility in the recommendations would allow the use of less expensive baghouse techniques as long as the efficiency remains reasonably high.

The use of asbestos in construction and demolition will require a strict code of practice since control of total emissions is difficult. This is seen to be one of the major sources of ambient asbestos in Ontario. Already, British and American authorities have banned outright the use of asbestos spray insulation and this has raised concern among industrialists in Canada.

The asbestos mining operations in Ontario are small compared to the total mineral output of this province. Financially, asbestos amounted to 2.9% of the Ontario mineral output of $1.53 billion in 1972 and 2.1% of $1.78 billion in 1973.(76) Still, the mining and milling of asbestos has the largest estimated emission factor of any asbestos operation and must therefore be considered a major source of asbestos emissions in Ontario. Because of the varied number of sources in each operation, a design standard is not practical or applicable by itself. Therefore, it is suggested that it can be coupled with a strict code of practice.

Shipbuilding operations can be extremely dangerous emitters of asbestos, as British experience has shown, but they have largely been ignored in this report. Analysis of this industry shows that only 1 to 3 ships (approximately 700 feet) are built each year.(80)(82) Ship repair firms are few in number and generally small operations.(81) Any large asbestos operations encountered by the shipbuilders are contracted out to Huron, Superior or Johns-Manville in Toronto.(82) Any asbestos work done by the builder or repairer is carefully handled but, supposedly, little is encountered.(79)(80)(81)(82) All asbestos is in sheet form as the spray application has not been used for at least 10 years.(81) Appendix 05.A lists all Ontario shipbuilders and ship repairers.

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06. MEASUREMENT TECHNIQUES

06.01 INTRODUCTION

Reliable equipment and techniques for determining the concentration of pollutants in the atmosphere are important for 3 reasons:

(1) to establish levels of hazardous contaminants in the environment
(2) to determine effectiveness of abatement measures
(3) to appraise contamination from source to receptor

It is rarely possible to make an absolute measurement of the characteristic of an airborne dust which is directly responsible for its biological effect. To be practical, measurement for the purpose of assessing a hazard and evaluation, must not only be convenient and relevant, but also permit the use of statistically adequate sampling strategies.

Early studies of health hazards in the United States asbestos industries (Fulton, et al, 1935, Dreessen, et al, 1938) were made with the same instruments and techniques used in studies of dusts associated with granite finishing and cement manufacturing.(2)(9) Midget impinger and optical microscope count data was used to estimate asbestos dust exposure.(2)(9) All of the dust particles seen were counted so, consequently, the resulting concentration was a measure of overall dust levels rather than a specific measurement of the asbestos concentration.

Because the epidemiologic studies of occupationally exposed asbestos workers in the U.S. were based on the impinger/optical microscope method, it was adopted as a "standard".(9) This method was satisfactory at the time since exposures were massive, but as dust levels reduced, it became necessary to measure the biologically appropriate attribute of the

the dust cloud. For example, at equal levels of overall dustiness in the occupational setting, the concentration of asbestos was found to vary considerably from textile manufacturing (75-85%) to insulation operations (5-15%).(2) The impinger method, although used by most agencies in the United States until the late 1960's(8) was not sensitive enough to make these accurate determinations.

During this period, the British method of monitoring air in asbestos plants consisted of counting fibres collected on membrane filters. The American and British methods were compared by Ayer *et al* in 1965 by parallel sampling of the same pool of air.(9) The samples were examined using phase-contrast microscopy at 430 X magnification. The use of the membrane filter was later refined and adapted by Edwards and Lynch in 1968, by relating the fibre count obtained with the phase-contrast microscope to the mass of asbestos determined by chemical analysis for magnesium. (The magnesium was assumed to come from asbestos.)(9)

In 1965, air pollution researchers began a preliminary investigation of total airborne asbestos by examining ambient particulate matter with dispersion staining and light field optical microscopy. By this technique, total asbestos could not be identified or quantified. In 1966, ambient air samples taken on membrane filters were examined for submicron asbestos particles by electron microscope. Sections of the filter were dissolved in acetone, the acetone washed out with water, and the sample transferred to a coated grid. The grids were examined, and asbestos fibres were photographed at 15,000 X. The characteristic tubular chrysotile structure was clearly discernible in some of these photographs.

At present, the accuracy or even precision of the various proposed methods is not known, and the research is of a very recent nature and is now being intensified as numerous environmental bodies try to establish a standard sampling and analytical method for asbestos in ambient air.

There are three important distinctions between occupational and ambient air monitoring with respect to asbestos.(36)

(1) There are far more fibres in in-plant air.

(2) It is easier to obtain a useful standard for identification purposes in an occupational situation since the source of the asbestos is known.

(3) Standard for occupational exposure refers only to those fibres greater than 5 um. in length.

For these reasons, the techniques used for monitoring the asbestos concentrations in industrial air are not suitable for ambient air analysis.(7)(10) Thomson reports that asbestos concentrations in urban air are one part in 5,000 of particulate matter and much less in a non-urban atmosphere.(9) Information from the State of California suggests that a sample filter of ambient air will contain 10,000 times as much non-asbestos as asbestos material by weight and the number ratio of particles may range from 10,000 to 100,000 non-asbestos particles for every asbestos fibre.(36) Asbestos fibres in ambient air are shorter, of less diameter and of much smaller concentration than those found in occupational settings and cannot be accurately identified with occupational monitoring techniques.

06.02 SAMPLING PROCEDURES FOR AMBIENT AIR

It is well recognized that sample collection is the most important step in any analysis of air pollution.(3)(6) The techniques used must give an unbiased representation of those particles which are present.

Sampling methodology selection for asbestos should be based on these two criteria:

(1) The method must collect asbestos particles in the required (respirable) range.

(2) The method must be as convenient, relevant and practical as possible, yet efficient so that it will ultimately be suitable for a large sampling network such as the E.P.A. or Environment Canada.

The sampling techniques that will be considered here are cascade impaction, liquid impinging and membrane filtration.

06.02.01 CASCADE IMPACTORS

The cascade impactor collects particles according to aerodynamic size on its various stages. The Battelle Institute determined by transmission electron microscope that asbestos fibers and fibrils were present on every stage of the impactor, showing that there is no obvious segregation according to size by this sampling technique.(1) They observed that, in the impactor samples, asbestos very often was collected as loosely agglomerated fibers and fibrils in association with other particulates.

06.02.02 IMPINGERS

Samples collected with all-glass impingers, as described by Battelle, contain a large amount of non-asbestos particulate so, for this reason, the technique has been considered not applicable without the benification of asbestos.

06.02.03 MEMBRANE FILTERS

Plastic membrane filters are considered by most authorities to be the most acceptable sampling method, primarily because of their low ash content, lack of fibres of any kind, and adaptability to field sampling procedures. Millipore and, more recently, nuclepore filters are recognized as the most efficient.(1)(12)(20)(23)

06.02.04 COMPARISON BETWEEN MILLIPORE AND NUCLEPORE FILTERS

Lately, several authoritative sources have recommended the use of nuclepore filters over millipore filters.(12)(20)(23) Nuclepore filters are transparent, nonhygroscopic with very smooth surfaces giving a uniform background on which fibres can easily be distinguished.(12)(20) They are very suitable for visual or automatic evaluation.

In the opinion of Spurny *et al*, there are two main disadvantages with the membrane filter method.(12)

(1) During the ashing and ultrasonic treatment, the sizes, and shapes of the deposited asbestos fibres can be changed significantly.

(2) The membrane filters are 100 um or thicker (except nuclepore which is 10 um thick) and their outside structure is irregular. Some small fibres and fibrils can penetrate the filter during the air sampling procedure and during the subsequent filtration of the liquid suspension through it. Also, some small fibres and fibrils can be lost to the inside structure of a membrane filter and cannot be detected by the electron microscope.

Nuclepore filters, manufactured by etching tracts of high energy particles through polycarbonates,(20) have no inside structure.(12) The pores are approximately monodisperse and the filter thickness is approximately 10 um. There are practically no losses of fibres and fibrils inside the pores.

The most effective separating mechanisms are sieving and direct interception. The random orientation of fibres during the flow through the filter pores plays an important role. There seems to be general consensus that Millipore AA or similar 0.8 um membrane filters will collect 90% of asbestos in air(14) but, nuclepore filters with the mean pore size of 0.2 um have an efficiency coefficient for asbestos fibres in the ambient air of about 95-98%.(12)(23) As Spurny *et al* report, if the total particulate concentrations in the ambient air are very high (large towns and industrial areas), sampling by means of nuclepore filters in a series is very suitable, because more than 50% of non-fibrous particulate mass can be pre-separated.(12)

The University of Waterloo Research Institute, after an intensive comparison study of Gelman (type GA-6; pore size .45 um) filters, millipore (type "AA"; pore size .8 um) filters and nuclepore (pore size .4 um), recently recommended nuclepore filter sampling technique in conjunction with the scanning electron microscope as an analytical method.(23) Beckett agrees that these two methods go well together as there is difficulty in discriminating between particles and fibres on millipore filter surfaces.(20)

There are two main disadvantages with the nuclepore filters:

(1) ordinary solvents will not dissolve the filter

(2) there is a higher pressure differential across the filter than with the Gelman or Millipore filters as the University of Waterloo Research Institute discovered.

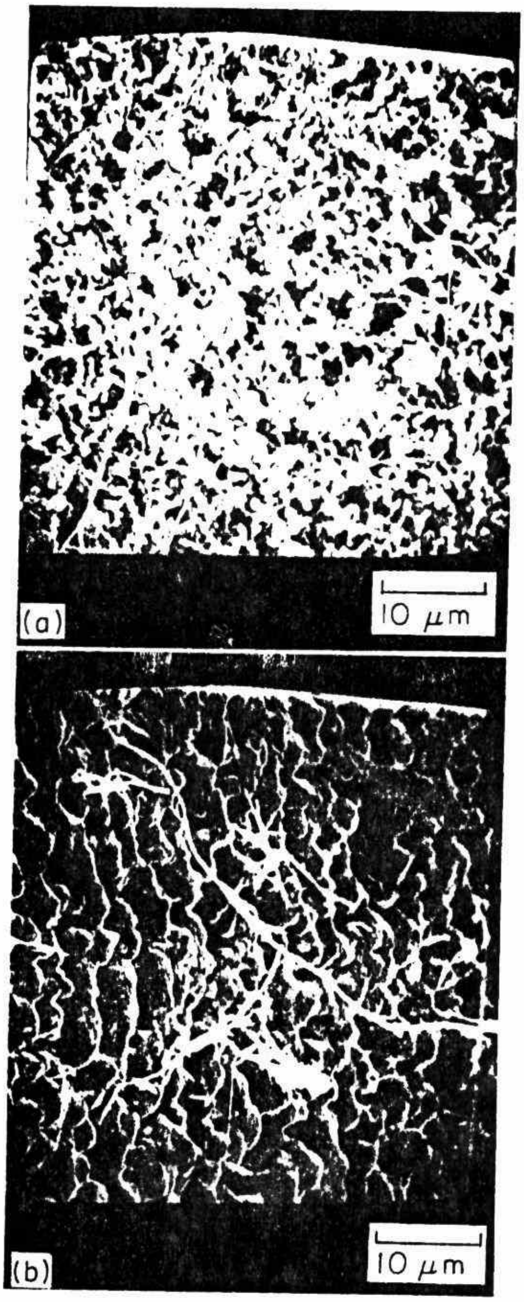
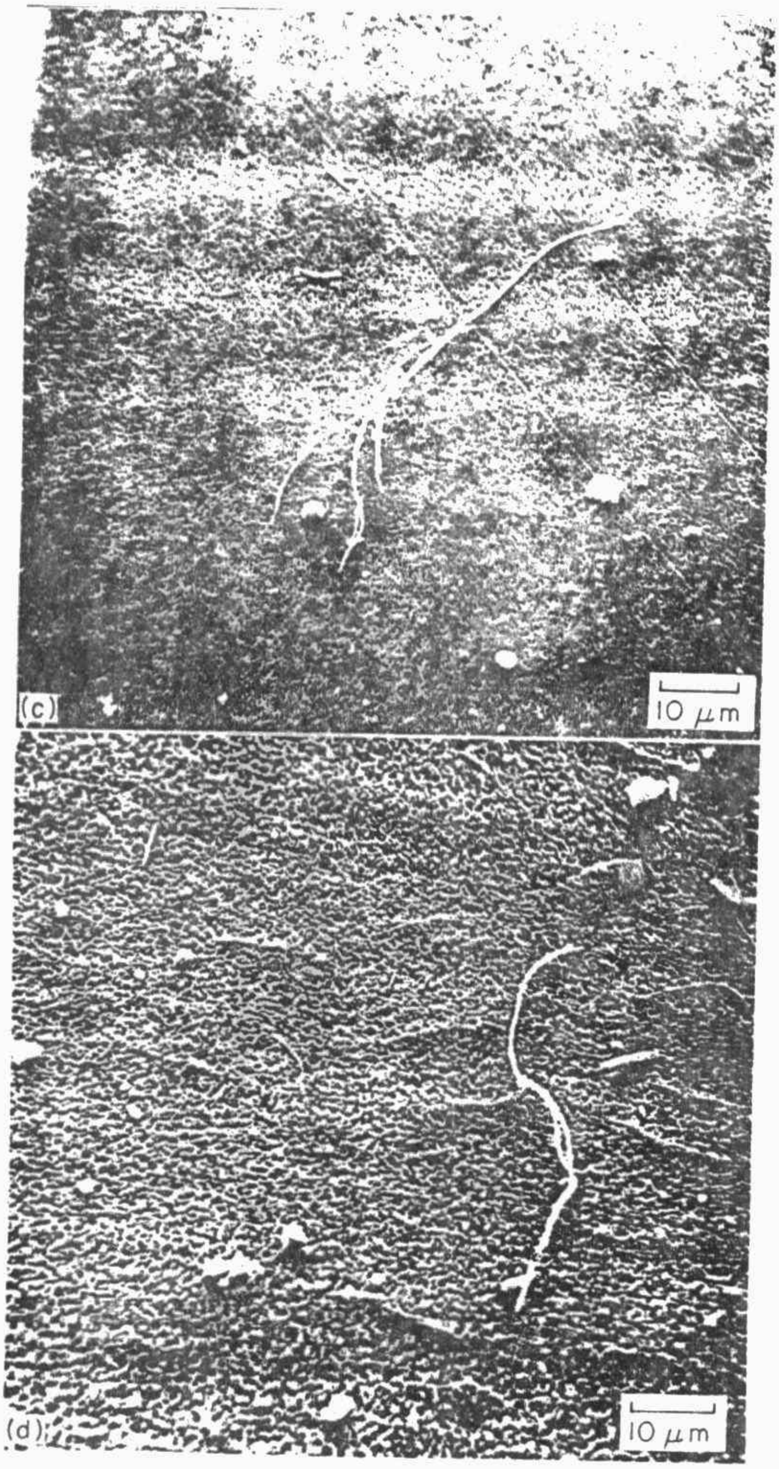


FIG. 1. Scanning electron photomicrograph of chrysotile asbestos: (a) sampled on a cellulose ester membrane filter; (b) sampled on a silver membrane filter; (c) sampled on the smooth surface of a Nuclepore filter; (d) sampled on the dull surface of a Nuclepore filter.


(c)
10 μm
(d)
10 μm

06.02.05 SAMPLING FLOW RATES

When selecting a sampling method, the concentration to be expected is an important criterion. If the sampling location is not near any obvious source of asbestos, few asbestos fibres will be expected and high demands will be placed on the method in terms of selectivity and sensitivity.(7) Sampling rates, durations and expected concentration levels should be coordinated to limit the number of fibres per counting field.(4) On the other hand, the longer the sampling period, the less attractive the sample is, since it will not be representative of the desired period.(7) The University of Waterloo Research Institute recommends anywhere between 45,000 and 450,000 fibres to be deposited on a 37 mm. diameter filter disc for the most accurate countability.(4) Although this figure was given in connection with occupational air sampling, G.M. Bragg confirmed these estimates for clear analysis of ambient air sample filters.(38) For counting fibres, it is important to have about 5 fibres per field of view. Less than 5 gives poor statistics and more than 5 are difficult to count due to crowding.(14)(38)

When sampling, the filters should be face down to prevent large particles from settling on the membrane and the sampling points placed well above street level, away from direct sources of contamination.(10) High volume sampling techniques are generally used but the flow rates and filter velocities range widely. For ambient air monitoring, the Air and Industrial Hygiene Laboratory method (State of California, Department of Health) employs .8 um pore size nuclepore filters of 47 mm. diameter, at a flow rate of 10 liters per minute, for 2 to 24 hours.(36) Rickards sampled 1,000 cubic metres (pore size .05 um) of ambient air while Mueller used the same sample size with a cellulose membrane of pore size .8 um.(11) Spurny et al sampled 10 cubic metres of ambient air with a 35 mm. diameter nuclepore filter series, the first with a pore size of 5 um and the second with 0.2 um pores.(12) They used a face filter velocity of 15 cm/sec. Selikoff and his associates, during their experiments, used an 8" X 10" Millipore filter with pore sizes of .8 um and 1.2 um in conjunction with high volume samplers working at 40 cubic feet per minute.(16) They found a range of 10 - 100 X 10^{-9} gm/m^3 of asbestos on their filters.

Millipore®, the manufacturer of the filter of the same name, recommends the 47 mm. diameter, 0.8 um pore size type "AA" filter to sample asbestos.(41) The maximum volume flowrate through the filter is dependant on the strength of the backing support screen and the differential pressure used.(37) Dr. Chatfield of the Ontario Research Foundation had suggested the use of .45 um pore size millipore filters for asbestos, but recently changed his recommendation to include nuclepore filters (although he recognizes that both have disadvantages).(39) The Waterloo Research Institute recommends .4 um pore size nuclepore filters.(23) Fifteen centimeters per second face filter velocity has been generally accepted and used most often by experimentors (most using 1 um pore size filter) in the past but, for the concentrations expected in ambient air, the long sampling time involved would be unsuitable. As one study has shown, face filter velocities of 265 cm./sec. or the corresponding flow rate of 156 L/min. (10 cm.^{2} effective filtration area) are not satisfactory for millipore filters as they have been shown to have a strong potential to be damaged. The same author suggests that, for long ambient air sampling periods, a face filter velocity between 38 - 100 cm./sec., or a maximum flow rate of 60 L/min., could be used for millipore filters. Nuclepore Corporation (ICN Canada, Montreal) indicate that maximum retention efficiency of the filter to flow rate ratio is similar to that of millipore (same diameter and differential pressure as millipore).(40) Although Nuclepore filters are thinner than Millipore, they are stronger, more durable and able to handle effectively larger volumes of air over shorter periods of time. For these reasons, Nuclepore filters seem the most suitable to sample asbestos concentrations expected in ambient air.

06.03 SAMPLE PREPARATION

Two general classes of sample preparation utilized to obtain size distributions by electron microscopy are the direct-clearing technique and the separation technique.(36) The direct method presents the microscopist with a sample on which a minimum of manipulation has been carried out, but which contains both asbestos particles and all other particles which were present in the environmental medium when the sample was collected. The separation technique presents a sample which contains a minimum of interfering particles, but which was prepared with much manipulation.

06.03.01 DIRECT-CLEARING TECHNIQUE

In many cases, it is possible to use the direct-clearing method to size and count asbestos fibres among the other material present. In this method, the sample filter is coated with a layer of silicon monoxide or carbon to hold the fibres in place. The filter itself is then dissolved by vapors of a solvent such as acetone or chloroform since the index of refraction of the asbestos and the filter are close.(3) The film with embedded fibres and other material is then usually examined by scanning electron microscopy.

The method is most suitable when:

(1) there is a larger (than usual) proportion of asbestos to particulate matter (ie., at a point source)

(2) when a representative sample is required as it appears

in ambient air, ie., little distortion of appearance of sample through manipulation (on the other hand, the asbestos may occur in clumps making accurate counting difficult)

(3) an even distribution of particulates is obtained by the filter.

06.03.02 SEPARATION TECHNIQUE

When a particulate sample, as collected, is so loaded that asbestos particles are obscured, a process is needed to:

(1) concentrate or beneficiate the asbestos particles

(2) provide means for redistributing the asbestos particles uniformly and in a countable frequency.

The first of these needs is accomplished by ashing, which removes organic particulate such as soot, and, when necessary, by centrifuging which removes inorganic particles which were large compared to the asbestos particles.(1)(7) The second of these needs was accomplished by ultrasonically dispersing the asbestos particulate in an aqueous media and refiltering the dispersed particulate.(1)(7) The refiltered asbestos particulate is then prepared for the electron microscope by the transfer replicate technique.(1)

Organic materials are eliminated by low-temperature combustion in oxygen. Low temperature ashing is a very slow (about 4 hours) oxidizing process that will keep the disturbance of fibres to a minimum(3) but there is some evidence to show that ashing changes the size, shape and composition of the fibre.(11)(36) The ashing treatment removes about half the total interfering particulate material. Heffelfinger et al of Battelle found that the low temperature ashing of the deposit on the membrane filter could best be done in an induction-coupled oxygen plasma at about 1-torr total pressure. If the collected sample and filter are ignited in air, there is a danger of sample loss because of the explosive manner in which the membrane filter burns. The chance of physical loss of particulates from the oxygen draft is virtually eliminated by placing the sample in a pyrex test tube with the open end in a position such that the oxygen plasma flows across the tube mouth normal to the axis of the tube. Possible contamination from the laboratory atmosphere is eliminated by using low temperature ashing, in which the atmosphere is tank oxygen.

06.03.03 ULTRASONIFICATION

The ash residue from the collected sample remains in the test tube, which is convenient for insertion into the ultrasonic bath that is necessary to break up agglomerates of particulates in order to provide a uniform deposit for the electron microscope.(7) The dry ash is suspended in water containing a surfactant and is dispersed by ultrasonic energy.(14)

Asbestos fibres are composed of fibrils of fairly constant diameter, but indefinite length. If the fibres are triturated, they will be reduced to fibrils which will be of random lengths. If the energy used in the fibre-reduction process is controlled, the fibril lengths will be random, but of a reproducible and tight size distribution. Ultrasonification has proven to be valuable for this process because of the repeatability of the energy utilized and the efficiency, as compared to other mechanical means or trituration.

Although ultrasonification changes the condition of the airborne sample,(1)(11) there is the advantage of having control of the amount of particulate deposited per unit area of filter since a selected volume of asbestos in the resulting liquid medium can be applied to a known filter area.

06.03.04 CENTRIFUGATION

Unlike the asbestos, the fly ash and most of the other particulates appear to retain the same size before and after ashing and dispersion by ultrasonic treatment. Therefore, centrifugation can be used for fractionation by size.(7) The larger particles settle, while the smaller asbestos particles remain in suspension. The ultrasonically dispersed aqueous suspension of ashed sample is centrifuged at 900 g. for about 30 minutes.(1) The supernatant portion is then skimmed off the top and filtered on a membrane filter. The precipitation is repeated a second time. It is estimated that centrifuging twice eliminated about 90% of the interfering particulates from most samples.(1) Studies of synthetic standards show that approximately 80 - 90% of the asbestos is recovered.(1)

Battelle's recommendation for beneficiation of ambient air samples is to ash every sample, but centrifuge only when necessary which, by experience, is needed only for a small fraction of the samples. Typically, 1/8 to 1/16 of the total sample is used for analysis.(1)

In conclusion, samples must be prepared in a manner to avoid changing fibre size distributions, losses and contamination. Losses may occur in ashing procedures, in excessive manipulation, in centrifugation and in aqueous filtration. For example, since more than 50% of chrysotile fibres are shorter than 0.8 um in length and more than 90% are less than 0.8 um in diameter, it is possible for a large portion of these fibres to be lost in aqueous filtration on 0.8 um pore size filters.(14)

06.04 ANALYSIS OF AMBIENT AIR SAMPLES

There are a number of techniques used with varying degrees of success for the counting and identification of asbestos fibres in ambient air samples. They can be divided into two groups:

(1) methods suitable to characterize large bulk samples of asbestos minerals: X-ray diffraction, infrared spectroscopy, differential thermal analysis, optical analysis and chemical analysis. These methods are generally of limited use in ambient air analysis and will be dealt with only for the sake of completeness.

(2) methods suitable for the identification of single fibres; electron diffraction, electron microprobe analysis, scanning electron microscope, transmission electron microscope.

06.04.01 X-RAY DIFFRACTION

X-ray diffraction is based on the phenomenon that the atoms that are vibrating around fixed points in the mineral act as centers of scatter.(7) The crystal structure is of decisive importance and it is possible to quantitatively determine the asbestos content in mineral dusts from calibration curves of intensity measurements of defined diffraction lines and X-ray interferences that are characteristic of the crystal.(24) The sensitivity of determination is approximately 0.5 mg. of asbestos provided the asbestos content of the dust is at least 3%.(7) Figures 2 and 3 are examples of X-ray **scattering patterns.**

There is usually little problem in the radiographic determination with sufficient accuracy of the chrysotile asbestos content of a sample, but amphibole asbestos generally gives a poor diffraction pattern.(11)(24) Massive and fibrous combinations have nearly coincident X-ray

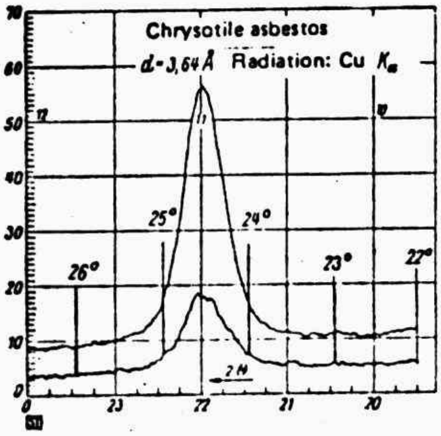


FIGURE 2. Diagram of the interference intensity of a slightly precrushed chrysotile asbestos after grinding in a high speed micro mill.

Reference (24)

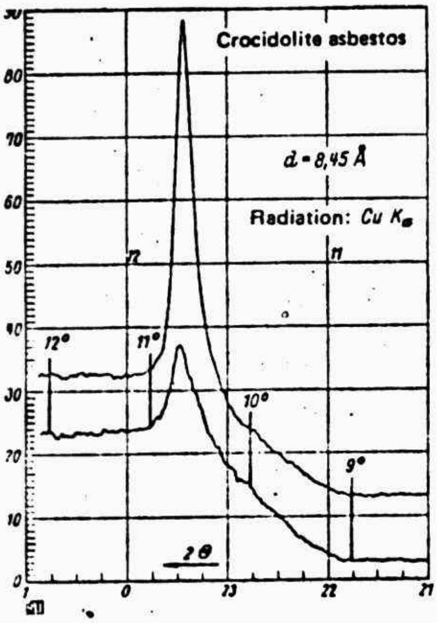


FIGURE 3. Diagram of the interference intensity of a crocidolite after grinding in a high speed micro mill.

Reference (24)

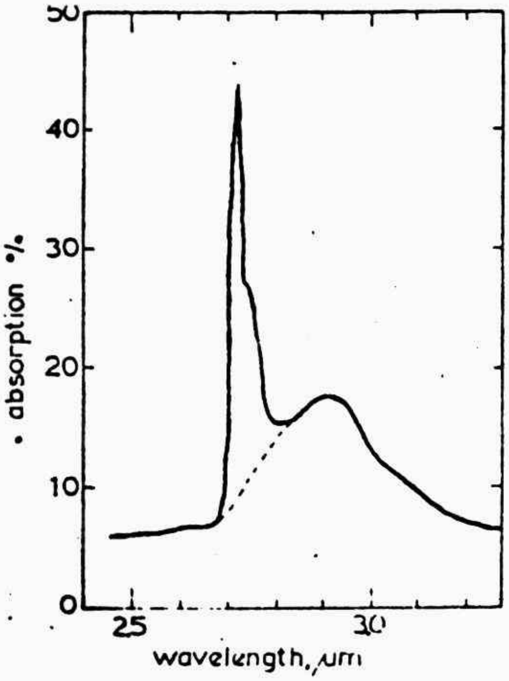


FIGURE 4. Infrared spectrum of chrysotile asbestos.

Reference (7)

diffraction patterns so, consequently, electron microscopy must be used.(11)

06.04.02 INFRARED SPECTROSCOPY

Infrared spectroscopy is based on the phenomenon that the vibrating atoms in the mineral can absorb energy. The position of the absorption bands in the IR region depends on the atomic groupings and type of bonding in the crystal.(24) However, only certain wavelengths can be used to magnify the amplitude of the vibrations of the atoms(7) and at these wavelengths, increased absorption of electromagnetic radiation occurs (Figure 4). The absorption spectrum is characteristic, and the extent of absorption is a measure of the quantity of asbestos.(7) The sensitivity of determination is approximately 10 ug, while the asbestos content of the sample should be at least 1%.(7)

Dust containing amphibole asbestos yields infrared spectra characteristic of the amphibole mineral group, but specific amphibole minerals can not be identified.(11) The infrared spectra of serpentine minerals are similar to other sheet silicates so that any mixtures of chrysotile with clays or talc make fibre identification impossible.(11)

06.04.03 DIFFERENTIAL THERMAL ANALYSIS

The amphiboles yield characteristic differential thermal analysis patterns which are inadequate for unequivocal identification, even in the pure mineral state.(11) Chrysotile produces a well-defined pattern, but tends to be extremely sensitive to changes in sample preparation and experimental conditions.(11)

06.04.04 OPTICAL AND CHEMICAL ANALYSIS

These are probably the most limited and least specific methods of analysis for ambient air, the qualities of inexpensiveness, ease, and time required make these procedures ideal for analysis of in-plant occupational air. Since the diameter of many of the asbestos fibres and especially fibrils found in ambient air are below the resolving power of the light microscope, this technique is totally unsuitable for the identification of asbestos.

Finally, it can be mentioned that when the air-borne dust contains high concentrations of asbestos, methods may be used that are not specific. Examples are atomic absorption and emission spectroscopy. Within their limitations, these are sensitive methods.

As asbestos is built up of elements which are very common such as magnesium, aluminum, and iron, these elements can only be used as indicators for the asbestos concentration if the concentration level of the asbestos is such that it stands out clearly against the always present background of these elements.

06.04.05 SELECTED AREA ELECTRON DIFFRACTION

High energy radiations other than X-rays are diffracted by asbestos matter, giving patterns related to the arrangement of atoms in the irradiated material and can be used like X-ray diffraction patterns to give similar information. A narrow beam of electrons passes through a thin crystal giving a pattern of spots (usually recorded photographically) very similar to the X-ray diffraction pattern.

This technique allows the differentiation of asbestos from non-asbestos materials and of chrysotile from amphibole asbestos.(36) Although chrysotile has a distinctive electron diffraction pattern, the patterns of amosite, anthophyllite, and crocidolite bear a close resemblance to each other, making positive identification difficult.(11)(36) Fibrils smaller than 0.05 um in diameter seldom produce diffraction patterns suitable for identification.(36)

Electron diffraction is often used in conjunction with another analytical tool but, since identification is slow and expensive, in most cases only 5% of the morphologically-identified asbestos fibres have their identifications confirmed by electron diffraction.(36)

06.04.06 ELECTRON MICROPROBE ANALYSIS

The electron microprobe analyzer makes possible X-ray spectrochemical analysis of small particles under an electron beam. The chemical composition of single fibres can be determined and asbestos fibres, especially amphiboles, can be chemically differentiated and identified on a single fibre basis.(11) The electron microprobe is capable of identifying asbestos fibres by composition provided that the fibre is large enough ($>$ 0.5 um) and is isolated from other particles that may contain silicon, iron, sodium or magnesium.(1) However, because asbestos fibres and fibrils were found by other techniques to occur in sizes much smaller than 0.5 um, the electron microprobe is of limited value in the identification of asbestos in collected air samples.

06.04.07 SCANNING ELECTRON MICROSCOPE

The scanning electron microscope permits rapid viewing and photography of materials and provides image resolutions down to about 100 Å.(1) Although a thin conductive coating must be frequently put on the surface of the sample, (this method is used in association with the direct-clearing technique described earlier) this method offers a faster and more direct method for examining small particles than does regular electron microscopy.(7) The scanning electron microscope requires little sample preparation and has an extremely large depth of field with the ability to determine shapes, sizes, surface structure and elemental composition.(23)

The sample is put on a grid and scanned at 1,000 X to determine uniformity of sample deposition, then the search for fibres is conducted at 8,000 X.(36) Each fibre detected is identified at 20,000 X morphologically and by electron diffraction for positive identification.(36)

A disadvantage of using the scanning electron microscope is the lower resolution (0.05 um) as compared with the transmission electron microscope (~ 0.001 um).(7) Another drawback is that it cannot unequivocally distinguish between forms of asbestos.(1) Identification is only possible by X-ray fluorescence analysis of the elements which constitute the particle under observation but, no information of crystal structure is given.(7) This is obtained by electron diffraction.(7)

Another disadvantage, as the Battelle Institute discovered, is that the scanning electron microscope images of the sample filter show the fibres more as clumps or "piled up" and interwoven groups rather than individual particles.(1)

06.04.08 TRANSMISSION ELECTRON MICROSCOPE

The transmission electron microscope is described as the basic tool necessary for the identification of asbestos fibres.(36) It is especially valuable for determining particles less than 1 um.(23) The lowest practical level of detection with the scanning electron microscope is 10^{-14} grams, while the transmission electron microscope is approximately 10^{-15} grams (resolving power to .001 um).(7)(23) Although, in principle, there is no limit to the amount of other material which may accompany the asbestos, the percentage of asbestos which can still be detected in the sample is a function of the time used to screen them.

Transmission electron microscopy is the best technique to date to provide unequivocal identification of asbestos fibres, as a study from the Battelle Institute reports.(1) The various forms of asbestos can be identified by their individual morphologies.(11) Identification is conducted at approximately 30,000 X.(1)(7)

Though electron microscopy if time consuming and therefore an expensive analyzing tool, it is at present, by many orders of magnitude, the most sensitive detector available for the problem at hand.

A recently developed instrument called EMMA which is a combination transmission electron microscope and electron microprobe analyzer, may in time become the ideal instrument for the detection and identification of very fine asbestos particles.(36) The electron microprobe enables the miroscopist to obtain an elemental analysis of a specific fibre for which morphological and selected area diffraction have been made, thus enhancing the certainty of identification.

The electron microscopic dark-field screening technique is an application of the optical microscopic principle that dark-field images of amorphous particles are generally different from those produced by crystalline substances.(36) Thus, crystalline fibres can be readily distinguished from non-crystalline fibres. This procedure is advantageous (time-saving) in detecting asbestos fibres which often constitute only a small fraction of the total fibres present.

Another technique called the "rubout technique", measures the weight of asbestos present.(36) This is done by grinding all asbestos fibers into fibrils of fairly uniform size. These fibrils are then mounted on electron microscope grids for identification, sizing and counting. The weight of asbestos is estimated by calculating the total volume of asbestos fibrils and multiplying by the density of the asbestos type present. Since one large fiber can account for 99% of the weight present in an environmental sample, this method has limited value in assessing health problems.

06.04.09 COUNTING AND IDENTIFICATION OF AMBIENT AIR FIBRES

When counting the number of fibres in ambient air, it is unlikely that approaches that do not use the electron microscope will be effective. In fact, high order magnification of this instrument will be required. The Air Industrial Hygiene Laboratories (AIHL) demonstrated that most electron microscopes which operate at less than 8,000 X do not exhibit sufficient resolving power to morphologically identify asbestos.(14) Presumptive identification of chrysotile morphology can be made at 20,000 X.(14) Positive identification, though, must be conducted by electron diffraction. Kramer et al report that Cunningham used magnification of 20,000 X to count fibres while Biles scanned at magnifications of 30,000 X - 80,000 X.(11) According to Langer, identification and location of asbestos fibres and fibrils (thickness of 200 Å to 400 Å) required a magnification of 31,000 X with subsequent identification of the chrysotile variety confirmed at 217,000 X.(11) Selikoff considers the smallest magnification for identification purposes to be at least 20,000 X and probably over 40,000 X will be needed.(16)

In addition, to the fine diameter of the fibrils, many of them are quite short, in many instances with lengths of less than 1,000 Å. (16) When enmeshed in the sampling debris, not only is high magnification electron microscopy necessary, but visual scanning may be inadequate, and inferior to photographic recording. Langer found this method to give consistently greater counts than visual scanning by about 30%.(11) In an attempt to reduce the fatigue and human error inherent in counting asbestos fibres, the Unione Internationale Contre Cancer (UICC) recommends counting from photomicrographs.(11)

Each asbestos fibre variety is quite different chemically, physically, structurally and morphologically. Under industrial circumstances, there is usually no problem in knowing exactly what is being measured, since the materials being used are either well characterized or can readily be analyzed. But, in the analysis of ambient air, one of the largest sources of error is in the morphological identification. First, there are many man-made and natural fibres that resemble asbestos, and second, it is difficult to obtain suitable standards to make morphological comparisons as chemical and physical forces of the environmental media may, in time, cause a change in the properties of the fibres, ie. water can leach magnesium from chrysotile.

06.05 STANDARDIZED SAMPLING AND ANALYTICAL METHODS CURRENTLY IN USE BY SUPPORTING AGENCIES

Three classes of methods are currently in use for the determination of asbestos in air. The first, utilizing light microscopy, has been adopted by NIOSH only for the determination of occupational exposures. The second class, used by Johns-Manville, Mt. Sinai Hospital in New York and Battelle Institute expresses asbestos in the air as a function of mass by reducing all asbestos fibers to fibril size. The third, used by AIHL and UC School of Public Health, presents asbestos concentration in terms of number of fibers of a certain size, hopefully as they exist in the air.

06.05.01 Class I - LIGHT MICROSCOPY METHOD (NIOSH)

Samples are collected on membrane filters, a portion of which is rendered transparent on a microscope slide for direct counting at 430 X using phase contrast microscopy. Fibers longer than 5 um appearing in a Porton graticule are counted. Fibers of a diameter less than 1 um are not seen and thus only about 2% of the fibers actually present are counted.

06.05.02 Class II - MASS METHODS

A. Mt. Sinai School of Medicine, New York City

The Mt. Sinai School of Medicine samples asbestos with 8" X 10" Millipore filters in high volume samplers capable of 40 cu. ft./minute.

Mt. Sinai's analytical method, subsequent to ashing for removal of organic matter, disperses the ash in a nitrocellulose film by a "rubout" technique, followed by mounting on electron microscope grids for identification, sizing, and counting. The weight of asbestos is estimated by comparing the particle size distribution with that from known weights of ground asbestos. A recovery of 30% to 50% of added chrysotile is claimed for this method. ("Rubout" is described as a technique of rubbing the sample in nitro-cellulose between two microscope slides, breaking the asbestos fibers longitudinally into small particles, hopefully, individual fibrils.)

The entire sample is represented by eight 100 um by 100 um grid squares counted at 40,000 X. Total area counted is 80,000 um^2.

B. Johns-Manville Corporation -

The original Johns-Manville analytical procedure is identical to that described above, except that a small portion of the ash is examined by light microscopy at 500 X to reveal fibers having a diameter greater than 0.5 um. The authors note that they have never detected a single asbestos fiber of this size in ambient air samples.

The sample is represented by size "typical" fields photographed at 4,000 X. Total area counted is about 6 X 4,000 um^2 = 24,000 um^2. Elaborate counting and sizing rules have been developed to accurately estimate the asbestos volume for subsequent weight calculation. A single sample requires one week for analysis.

C. Battelle Memorial Institute, Ohio -

The Battelle Memorial Institute located in Columbus, Ohio, sample asbestos with a 47 mm. diameter type HA Millipore filter (.45 um pore size) in the corresponding Millipore aerosol filter holder.(1) An air sampling vacuum pump running at 12.5 l/min. collects 1.5 m^3 of air near a point source and 200 m^3 of air in ambient urban locations.(1)

The analytical method was developed by Battelle for the EPA. The sample is ashed and the ash is sonicated into fibrils, then suspended in distilled water. The suspension is filtered onto a cellulose ester Millipore filter. A carbon film is deposited on the surface of the fibers and the filter, after which the filter is dissolved in acetone. The fibers held in the carbon film are then counted as in the Mt. Sinai method. Five 100 X 100 um fields are counted at 30,000 for a total of 50,000 um^2.

06.05.03 Class III - FIBER COUNT METHODS

A. Air and Industrial Hygiene Laboratory, California -

The AIHL of the California State Department of Health sample for asbestos utilizing a 47 mm diameter type AA Millipore filter, 0.8 um nominal pore size, mounted in a 47 mm. diameter open type metal Millipore aerosol filter holder.(5) An air flow rate of 1-2 cfm was maintained by a Gelman air sampling vacuum pump for a time period of 2 hours.

In this method, the sample is not ashed, but instead, dissolved in acetic acid, methyl alcohol and methyl ethyl ketone. The sample suspension is transferred by filtration to a polycarbonate (Nuclepore) filter which is then coated with a layer of silicon monoxide. Small discs are cut from the coated filter, placed on electron microscope grids, and the filter dissolved in chloroform.

The fibers are counted directly on the viewing screen at 2,000 X. Twenty 112 X 112 um squares represent the entire sample, or a total area counted of 250,888 um^2. Total fiber concentration, regardless of fiber size, is reported.

The first method used by the Air and Industrial Hygiene

Laboartoary mixes the ashed sample with a solution of Parlodion in amyl acetate. An aliquot of this suspension is dropped on a water surface within a confined area of known size.

Three electron microscope grids are drawn through the asbestos containing collodion film. Twenty random grid holes are counted on each of the three grids. Thus, 3 X 20 X 50 um X 50 um or 150,000 um^2 are counted and sized at 4,000 X.

For light microscopy, another collodion film is prepared from a new aliquot of the collodion suspension. This film is transferred to a microscope slide for counting at 430 X as specified by NIOSH.

AIHL's second procedure, the Direct Clearing Method, 3 mm diameter disks are excised from the Millipore filter and placed face down on a Formvar-coated electron microscope grid. Acetone vapors are used to dissolve the filter, leaving the collected material as a coating on the grid. Grids are dried and counted as in AIHL's Parlodion Film method.

B. Ontario Research Foundation -

At present, Ontario Research Foundation (ORF) is the most experienced at the measurement of low concentrations of asbestos is ambient air in Ontario. The first step in their procedure is to collect some of the solid material on a 0.1 um pore size membrane filter. In the case of air, about 5 m^3 is filtered. The membrane filter is then ashed in a clean glass vial using a plasma microincineration technique. The ashing takes place at low temperatures (typically 70°C) so no decomposition of the fibres can occur and organic materials and the filter itself are oxidized to CO_2. The residue is gently redispersed ultrasonically in filtered distilled water, and the suspension centrifuged on to a 1 cm. diameter glass cover disc. The disc is dried and a thin carbon coating is applied by evaporation. The carbon film is scored and floated off on to water, carrying the particles with it; pieces of this are then picked up on 200 mesh copper grids. A maximum of 10 grid squares is searched for asbestos particles at a magnification of about 25,000 X. Particles are identified at the instrument by electron diffraction, and measured in both length and width by comparison with a series of geometrically spaced calibration circles scored on the fluorescent screen of the microscope.

The particle counts are processed by a computer program, which calculates the particles, number and mass concentration. It also plots the number and mass size distributions. Using the sample volumes specified, air concentrations can be measured down to about 0.01 fibres/cc.

06.05.04 DISCUSSION

When mass methods are used, physicians are given no idea of the respirable asbestos present in the air or its size distribution. Fibre count procedures have the advantage of the possiblity of presentation of the size distribution of the asbestos as it is collected from the air. All three procedures suffer from inaccuracies in volume estimation when attempts are made to relate size distribution to a mass concentration.

The Battelle method, in addition to possible errors incorporated in the weight measuring method, may suffer possible losses of large fibres by centrifugation and small fibres by aqueous filtration.

The Direct Clearing Method may not be used for long sampling periods or in highly polluted air, since minute fibrils will be hidden by large amounts of particulate matter.

The AIHL procedure and the O.R.F. method involve more sample handling than any other method, and therefore, are probably subject to more manipulative losses. Samples in the California method are not ashed leaving solvent-insoluble organic matter which may obscure minute fibrils. Minute fibrils may also be lost in the filtration step.

FOR BIBLIOGRAPHY OF SECTION 06
REFER TO THAT OF SECTION 07

07. AIR QUALITY MEASUREMENTS

07.01 INTRODUCTION

There is, at present, no practical absolute method for the routine measurement of exposure to airborne asbestos fibres.(8)(12)(36) Different agencies have developed different methods, each measuring something a little different so, therefore, the methods do not correlate well. Even values using the same analytical method, but obtained by different laboratories often do not agree. Ratios between results by different methods can be used for qualitative purposes only.

07.02. FIBRE/MASS RELATIONSHIP

With this in mind, it can be easily understood why the units of measure of airborne asbestos vary widely. Comparisons between results involving different units are difficult as conversion factors are, at best, only approximations. Dr. Thompson has reported that there are approximately 100 fibrils per asbestos fibre and 100,000 fibrils per nanogram.(9) Spurny et al assumes 100 fibrils per fibre but 10^6 fibrils per nanogram.(12) Timbrell feels that there are "many hundreds of fibrils in a fibre".(29) Meijer states "a large fibre may fracture longitudinally into a thousand smaller fibrils in air, water or biological fluids."(7) Dr. Nicholson and his associates state "one nanogram of chrysotile asbestos could represent a million fibrils".(30)

There is no argument among authorities today as to the presence of asbestos fibrous particles under 5 um in length but, there is controversy regarding the quantities involved with estimates ranging from only 2% to 10% of the total inhaled asbestos being greater than 5 um in length.(8)(9)(30)

Compared to other contaminants, the amount of asbestos in suspended particulate matter is very small.(10) Asbestos has been estimated by Thompson at one part per 5,000 of particulate matter in urban air and much less in non-urban atmospheres.(9) Other reports suggest 10,000 to 100,000 particles for every asbestos fibre.

Leonard Bruckman of the Department of Environmental Protection, State of Connecticut, devised a conversion formula, using the available data as a basis, equating 20 asbestos fibres greater than 5 um (or 1,000 actual fibres) to one nanogram. A panel discussion at the 67th Annual Meeting of the Air Pollution Control Association in Denver, Colorado, June 9-13th, 1974, held after Bruckman's presentation of his paper, only mildly criticized his conversion factor,feeling it to be conservative.(47)

Detected and enumerated asbestos fibres have been expressed in various ways by various agencies:

(1) fibre size distribution
(2) total asbestos fibre count
(3) volume and mass of asbestos fibres

Many uncertainties are involved in the evaluation and interpretation of results expressed in these categories. For example, a 10 um long asbestos fibre may break into many shorter fibre pieces during the investigation.(11) Heterogeneity of size is very important in accurately determining the character of the ambient air sample as it appears in air and it has been proven that maniupulation of the sample can destroy this character. Total fibre counts are strongly influenced by the particles of the smaller lengths and diameters which make less important contributions to the total volume and mass of fibres. Consequently, these particles have relatively little effect on weight-average values.

Mass measurements, in addition to being more easily comparable, provide a more stable estimate of asbestos since fibre size distributions change with different ambient air emission sources and the distances from which the sampling took place.(16) Equal numbers of fibres can represent signficantly different amounts, by weight, of asbestos. Again, though, measurements by weight can be strongly biased by the large fibres. Still, Lynch et al suggest that because of the difficulty to obtain close agreement on fibre counts within the lab and especially between laboratories, plus the tediousness of counting, mass measurements should be made whenever appropriate.(8)

Fibre size distribution is important no matter how the sample is analyzed. At present, to obtain such a distribution is time-consuming and expensive and the presence of other material and existing transfer and sampling methods may distort the observed fibre distribution. However, experience in recent studies (ie., California(14)) suggest that these problems can be overcome. Fibre size distributions are necessary to determine the character of the asbestos in the ambient air and any legislation to regulate asbestos emissions should be based initially on this data. Weight estimations may prove to be a good monitoring technique in association with the general fibre size distribution curve for that particular emission source.

It is not currently known how strongly the biological effect is dependant on fibre size and probably only further medical research will outline the correct parameter requirements for the evaluation and interpretation of ambient air samples.

TABLE 1

ASBESTOS CONCENTRATIONS AS MEASURED IN AMBIENT AIR

SPECIFIC SITES AND POINT SOURCES

LOCATION	ASBESTOS CONCENTRATION	MEASURING AGENCY *	REFERENCE
Upwind of asbestos plant, California.	57 ng/m^3 or 16 X 10^6 fibrils/m^3	A.I.H.L. California	(26)
Downwind of same asbestos plant, California.	11,000 ng/m^3 or 100 X 10^6 fibrils/m^3	A.I.H.L.	(26)
Los Angeles Freeway Loop Sites	0 f/L - 12 f/L or 0.0 f/m^3 - .012 f/m^3	A.I.H.L.	(13)
Los Angeles Freeway (General)	4.6 - 6.4 fibres/L or .0046 - .0064 f/m^3	A.I.H.L.	(26)
New York City Construction Site #1	45 - 180 ng/m^3	Mt. Sinai	(16)
New York City Construction Site #2	15 - 30 ng/m^3	Mt. Sinai	(16)
New York City Construction Site #3	20 ng/m^3	Mt. Sinai	(16)
New York City Construction Site #4	45 ng/m^3	Mt. Sinai	(16)
New York City Construction Site #5	20 ng/m^3	Mt. Sinai	(16)
New York City Toll Booth	100 - 160 ng/m^3	Mt. Sinai	(16)
New York City Freeway Exit Ramp	100 ng/m^3	Mt. Sinai	(16)
N.Y.C. Long Island Expressway, 1/4 mi. from toll booths	30 ng/m^3	Mt. Sinai	(16)
Lockland, Ohio Police Station	62 - 170 ng/m^3 Average 110.66 ng/m^3	Battelle	(1)

Cont'd...............

TABLE 1 (Cont'd)

SPECIFIC SITES AND POINT SOURCES:

LOCATION	ASBESTOS CONCENTRATION	MEASURING AGENCY *	REFERENCE
Wyoming, Ohio Municipal Building	24 - 33 ng/m^3 Average 28.5 ng/m^3	Battelle	(1)
Lincoln Heights, Ohio City Hall	11 - 1800 ng/m^3 Average 396.75 ng/m^3	Battelle	(1)
Lincoln Heights, Ohio Mathews & Dixie Streets	17 - 600 ng/m^3 Average 141.71 ng/m^3	Battelle	(1)

*** Refer to 06.05 for method.**

TABLE 2

ASBESTOS CONCENTRATIONS AS MEASURED IN AMBIENT AIR

REGIONAL MEASUREMENTS (Average of Several Stations):

LOCATION	ASBESTOS CONCENTRATION	MEASURING AGENCY	REFERENCE
San Lucas, California 5/15/72	1 X 10^6 fibrils/m^3	A.I.H.L. California State Dept. of Health	(26) (14)
San Lucas, California 9/25/72	2 X 10^6 fibrils/m^3 or 110 ng/m^3	A.I.H.L.	(14)
King City, California 9/25/72	1 X 10^6 fibrils/m3 or 175 ng/m^3	A.I.H.L.	(14)
Berkeley, California 2/10/72	0.7 X 10^6 fibrils/m3 or 73 ng/m^3	A.I.H.L.	(26) (14)
Berkeley, California 11/30/72	0.3 X 10^6 fibrils/m3 or 22ng/m^3	A.I.H.L.	(14)
Manhattan, New York City	25 - 60 ng/m^3	Mount Sinai Research Institute	(16)
Bronx, New York City	25 - 28 ng/m3	Mt. Sinai	(16)
Brooklyn, New York City	19 - 22 ng/m^3	Mt. Sinai	(16)
Queens, New York City	18 - 29 ng/m^3	Mt. Sinai	(16)
Staten Island, New York City	11 - 21 ng/m^3	Mt. Sinai	(16)
Philadelphia, Pennsylvania	45 - 100 ng/m^3	Mt. Sinai	(14) (16)
Ridgewood, New Jersey (Suburban)	20 ng/m^3	Mt. Sinai	(14) (16)

Cont'd...........

TABLE 2 (Cont'd)

REGIONAL MEASUREMENTS (Average of Several Stations):

LOCATION	ASBESTOS CONCENTRATION	MEASURING AGENCY	REFERENCE
Port Alleghany, Pennsylvania	16 - 36 ng/m^3	Mt. Sinai	(14) (16)
Dayton, Ohio	.04 - 11.0 ng/m^3 Average 4.34 ng/m^3	Battelle Columbus Laboratories	(1)
Houston, Texas	4.0 - 6.0 ng/m^3 Average 4.5 ng/m^3	Battelle	(1)
Pittsburgh, Pennsylvania	2.0 - 8.0 ng/m^3 Average 4.33 ng/m^3	Battelle	(1)
San Francisco, California	1.5 - 40.0 ng/m^3 Average 14.83 ng/m^3	Battelle	(1)
Washington, D.C.	1.6 - 40.0 ng/m^3 Average 12.05 ng/m^3	Battelle	(1)
Cincinnati, Ohio	20 - 60 ng/m^3	Battelle	(1)
Frankfort, Kentucky	.024 - .147 ng/m^3	Battelle	(1)
Urban Sites (General)	0.5 - 15 ng/m^3	E.P.A.	(9)
Non-Urban Sites (General)	0.1 ng/m^3	E.P.A.	(9)
Most Urban Sites	Less than 15 ng/m^3		(48)
Heavily Conjested Urban Sites (ie. N.Y.C.)	Above 30 ng/m^3		(48)
Non-Urban Sites	Less than 1 ng/m^3		(48)
Remote Sites	60 $fibres/m^3$ or .06 ng/m^3		(9)

FIG. 1. Particulate matter filtered from London air.

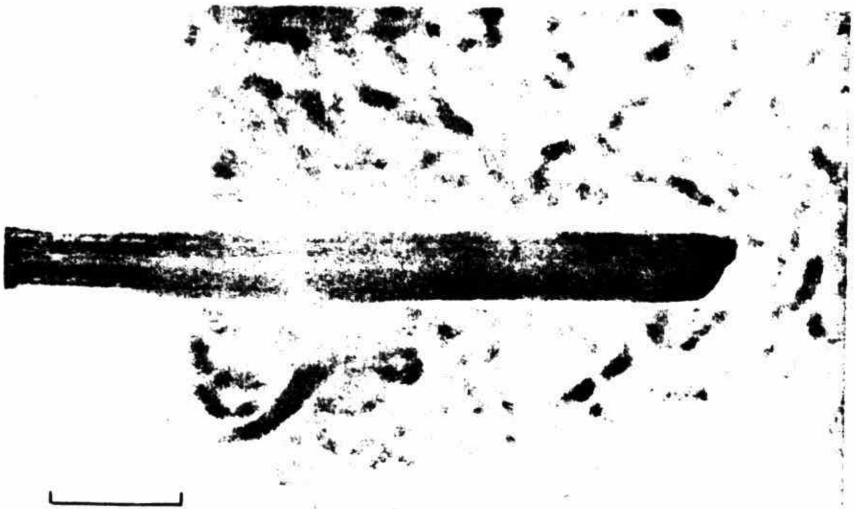


FIG. 2. A single fibre, probably an ultimate fibril of chrysotile, filtered from the air of Düsseldorf. Most fibres appear to be contaminated with soot and tar so that definition is poor, but the central core and fine structure is visible.

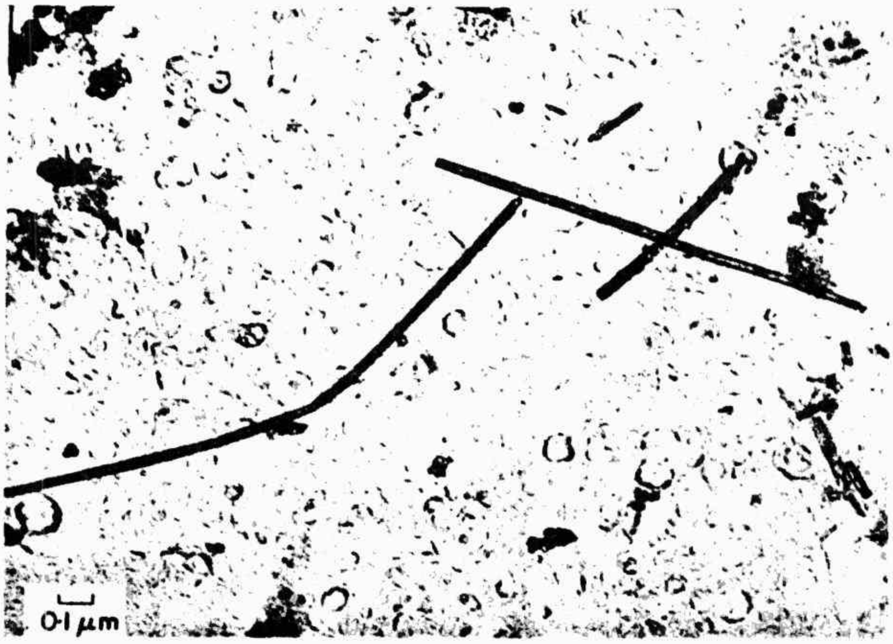


FIG. 3. Single fibrils filtered from London air. The fibril dia. is about 0·04 μm, typical of chrysotile. The fine structure shows changes similar to those observed when chrysotile is heated.

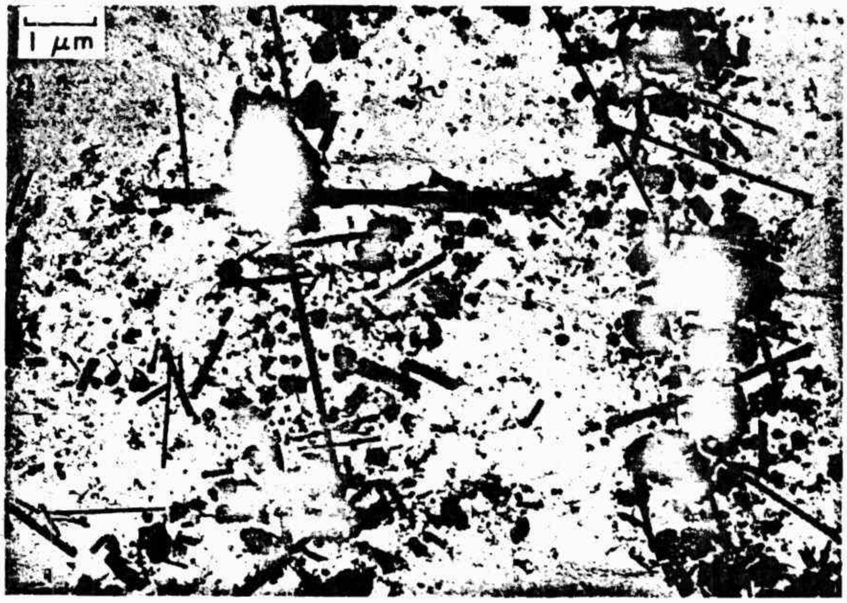


FIG. 4. An agglomerate of fibres collected on a filter at the top of a building in London.

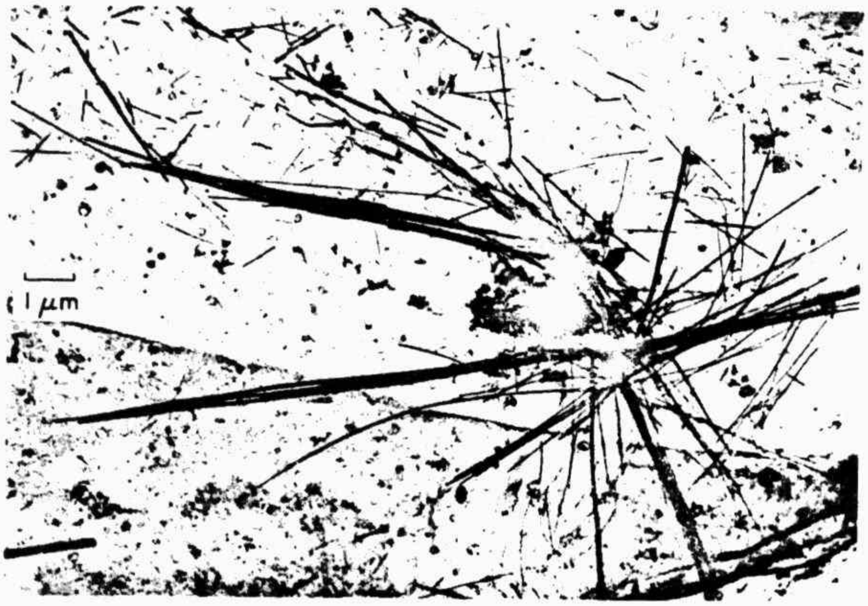


FIG. 5. An agglomerate of fibres collected on a filter at the top of a building in London.

07.03 MEASUREMENTS OF ASBESTOS IN AMBIENT AIR

Tables 1 and 2 list actual measurements of asbestos concentrations made in ambient air. Some of the samples are regional (ie., several stations distributed around the city determining the average level of asbestos in air) and some are local or point source samples (measurement of ambient air directly around an asbestos plant or construction site). Regional comparisons show non-urban and rural airborne asbestos concentrations are typically less than 1.0 and 0.1 ng/m^3 respectively.(9)(48) Urban areas have asbestos concentrations below 30 ng/m^3,(48) usually between 0.5 - 15.0 ng/m^3,(9) except in heavily industrialized areas (ie., Manhattan, New York City, Philadelphia) and around construction sites and toll booths. The AIHL of the California State Department of Health considers there are approximately 3,000 fibers/m^3 near a source or 3 ng/m^3.(14) Thompson reports that data obtained by the E.P.A. procedure indicates that asbestos levels are about 2,000 ng/m^3 or 2 X 10^3 fibres/m^3 at a point source.(9)

07.04 FIBRE LENGTH DISTRIBUTION

Since hydrodynamic, aerodynamic and biological effects may depend upon fibre size, it is important to know the size distribution of asbestos in air. Column I of Table 3 shows the length distribution of standard UICC Canadian Chrysotile Reference Samples as determined by Vernon Timbrell. Column II gives AIHL's data on the same standard, while Column III gives the results on an air sample taken closely downwind of a California chrysotile asbestos mine. There is good agreement between AIHL's and Timbrell's data.

The AIHL analyzed the diameter of the samples as seen in Table 4 (and presented schematically in Figure 6) and found rough agreement between the ambient distribution and those obtained from the bulk

TABLE 3 (14)

FIBER LENGTH DISTRIBUTION (PERCENT)

Length (um)	Data with UICC Chrysotile B	AIHL Data on Chrysotile B	AIHL Data Near Chrysotile Mill
0.2 < 0.5	30.6%	16.3%	30.5%
0.5 < 1.0	33.4	28.7	34.1
1 < 2	19.8	25.3	14.0
2 < 5	13.2	23.4	8.0
> 5	3.0	5.8	5.5

TABLE 4 (14)

FIBER DIAMETER DISTRIBUTION (PERCENT)

Diameter*	AIHL Downwind of Source	Diameter*	AIHL UICC Standard
< 0.06	65.9	< 0.05	33.4
.06 < .125	13.2	.05 < .1	34.7
.125 < .25	12.4	.1 < .25	14.9
.25 < .5	1.5	.25 < .5	13.7
.5 < .75	3.1	.5 < .8	2.8
> .75	3.9	> .8	.6

* Different counting intervals used in the two studies.

reference material. In this sample, the median fibre length is 0.5 um and the media fibre diameter is 0.05 um.

The diameter distribution from Table 4 is shown in Table 5 for comparison with the mass distribution of the same sample. Therefore, it is evident that 90% of the fibres present, contribute less than 5% of the total mass, while 90% of the mass is due to a relatively small number of large diameter fibres. Only 5% of the fibres were greater than 5 um. and this sample was taken near a point source where ambient levels are expected to be higher than normal.

TABLE 5(14)

FIBRE DIAMETER VS MASS DISTRIBUTION

Diameter (um)	% Fibres	% Mass
< 0.06	65.9	0.2
.06 < .125	13.2	0.8
.125 < .25	12.4	2.9
.25 < .5	1.5	1.7
.5 < .75	3.1	18.5
.75 < 1.25	1.5	21.4
> 1.25	2.3	54.5

The fibre size distribution and the distance from the source is also an important consideration. Finnish experimentors Laamanen, Noro and Raunio reported air studies showing asbestos dust at distances up to 50 km. from the mines, including deposits ranging from 1.52 gm/100 m^2/month 4 km. away to 34.6 gm/100 m^2/month at 0.5 km.(51) Battelle Institute analyzed the fibre size distribution and distance from the source relationship in Table 6. The fibres with a higher length to width ratio tend to stay in the air longer.

TABLE 6(1)

SAMPLES COLLECTED BY THE BATTELLE CASCADE-IMPACTOR NORTH (DOWNWIND) FROM POINT SOURCE NEAR CINCINNATI, OHIO (FEB.16/71)

(2-Hour Collection at 12.5 Liter/Min (1.5 m^3)

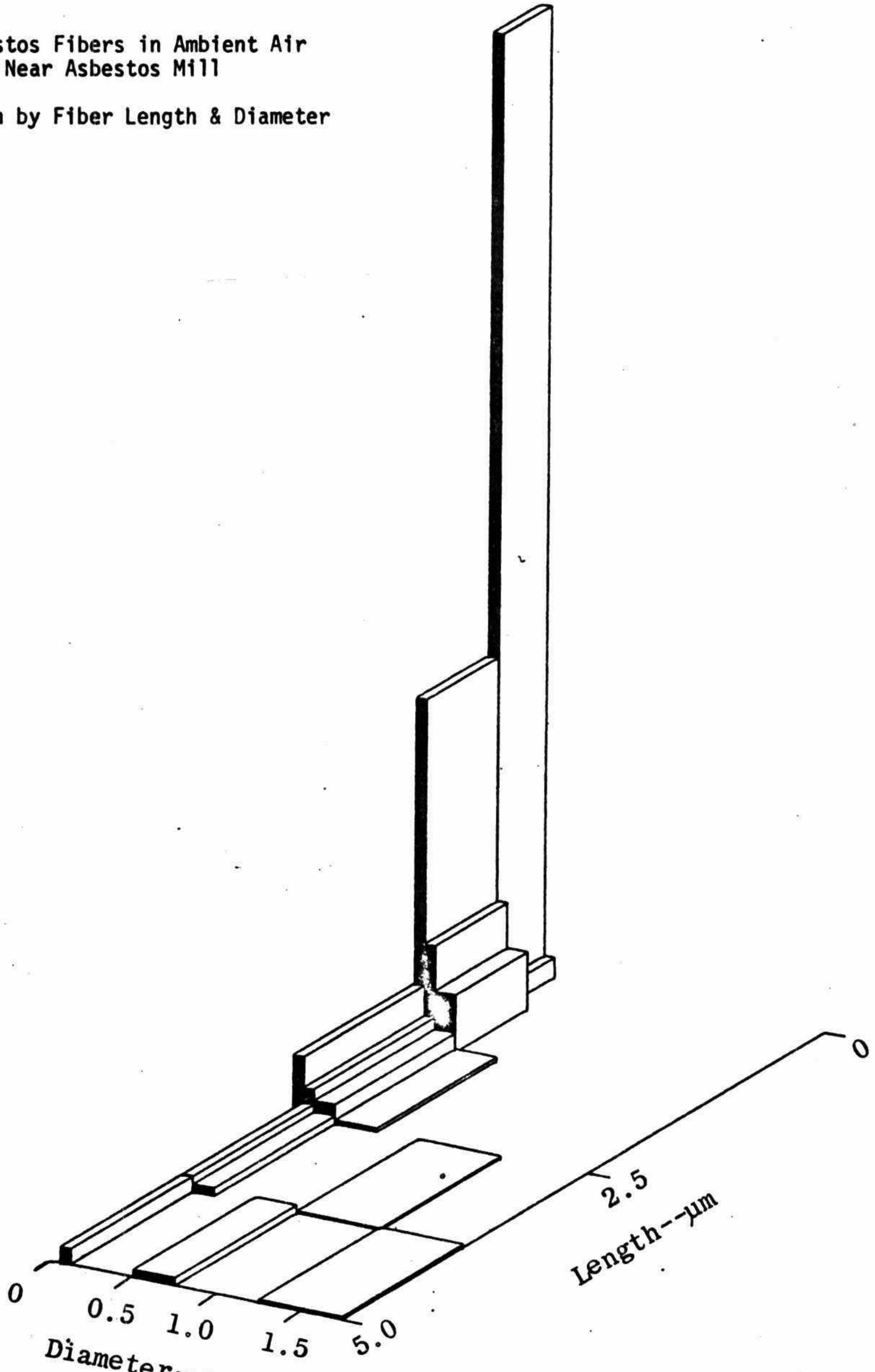
Stage	Stokes Diameter[a], µm	Asbestos ng
	1 Mile From Point Source	
1	> 16	4
2	8-16	40
3	4-8	25
4	2-4	12
5	1-2	18
6	0.5-1	5
7	0.25-0.5	8
	2 Miles From Point Source	
1	> 16	6
2	8-16	9
3	4-8	7
4	2-4	2
5	1-2	5
6	0.5-1	-
7	0.25-0.5	-

(a) - Diameter of particle of unit density which would be collected on the particular stage.

FIGURE 6.

Asbestos Fibers in Ambient Air
Near Asbestos Mill

Shown by Fiber Length & Diameter



Source: Reference (14)

07.05 CONCLUSIONS

The techniques for quantitative determination of small asbestos fibres and fibrils in ambient air are not yet satisfactory. Existing data concerning atmospheric concentrations is approximate and somewhat scanty. At present, there is little information regarding the accuracy or precision of the various methods, prompting some authorities to claim that the data obtained thus far from environmental monitoring is no better than an order of magnitude estimate.(12) A continuing research program in this field could lead to the development of an improved international standard method for measuring ambient concentrations of airborne asbestos.

There are advantages and disadvantages to both the weight and fibre count methods of analysis. A weight measurement is heavily biased by the large particles whereas a fibre count is biased by the small. But, if a fibre distribution is shown, then, although this is expensive, a realistic evaluation can be determined.

An accurate in-depth assessment of the situation in Ontario must be achieved before any comparisons can be made with other reported information. After the background data collection has been made, mass measurements in conjunction with the standardized fibre length distribution of that source may prove to be a less-expensive, relatively accurate, monitoring technique. Other monitoring measurement techniques include analyzing the end of the fibre length distribution (for example, all fibres over 4 um) for a particular source and then comparing this to the standardized distribution for that asbestos source.(38)

Environmental agencies have approached the problem of measurement units with caution. Occupational health organizations have agreed on fibre counts per unit of volume whereas some air pollution control agencies such as the State of Connecticut, Department of Environmental Protection, have decided on a standard based on measurements of mass. The California State Department of Health find it difficult to recommend either unit of measurement based on the extensive controversy over critical health questions.(59) If the long fibres prove to be the most toxic, there should be little problem in ambient air as few fibres are greater than 5 um long.(5) If the short fibres are also considered toxic, the weight measurement is biased by long fibres so it is felt, in this light, that a fibre count is the best analytical method.

The sampling technique to be suggested here utilizes 47 mm nuclepore membrane filters with a pore size of .4 um sampling at 40 L/min. for approximately 4-8 hours. The criterion is as follows:

1. Nuclepore filters have gained increasing popularity even within this last year. Experienced authorities in the field are generally changing their recommendation from millipore to nuclepore filters. They are stronger, thinner and easier to detect asbestos on, and capable of handling larger volume flow rates, but they have more flow resistance and a higher pressure drop over time.

2. 47 mm. is the largest diameter that can be used as ashing only removes about 99% of the organic material and filter and, with filters larger than 47 mm., the asbestos would be difficult to distinguish from the increased amount of residue.(39)

3. .4 um is recommended by Nuclepore Corporation literature (and other sources) for asbestos.(40) This pore size should be capable of trapping 98% of the asbestos in the airstream. Prefilter techniques have been discarded by this section.

4. For a 47 mm sample filter, a minimum of approximately 100,000 fibres would be needed for an effective count. Dr. J.P. Lodge, Jr. in conjunction with the National Center for Atmospheric Research in Boulder, Colorado, recommended the maximum flow rate for a .4 um, 47 mm. nuclepore filter to be 25-30 l/min.(54) Dr. Lodge indicated that a 40 L/min. flow rate was not excessive and preliminary experiments made by the Air Resources Branch substantiates this point of view. If the expected asbestos concentrations in urban ambient air range from .5-15 ng/m^3 (9) and a 40 L/min. flow rate is achievable, it would reduce sampling times to an easily manageable 4 hours (with concentrations of 10 ng/m^3; smaller concentrations will require longer sampling times).

Further laboratory testing of the method must be conducted before it can be used with reasonable assurance, but all indications for success of the method appear to be good. A recommended sampling program for Ontario is outlined in Section 10 of this report.

The membrane filter samples will be analyzed by transmission electron microscopy with the help of selected area diffraction and electron microprobe analysis. Conflicting reports as to the effectiveness of the scanning electron microscope make the value of this method undeterminable at the moment for asbestos, but it would appear that this analytical technique could prove to be an excellent monitoring device in the future. The accuracy of the transmission electron microscope is required for initial analysis procedures.

To accurately assess the true character of asbestos in ambient air in Ontario, sample manipulation must be kept to a minimum so as to reduce fibre breakage. Sample manipulation should be discouraged in laboratory analysis, but proven procedures should not be deviated from too much as the analyzer's experience is an important consideration in obtaining a good count.

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08. HEALTH EFFECTS

(To be presented by the Ontario Ministry of Health.)

09. STANDARDS AND CRITERIA

09.01 INTRODUCTION

In to-day's modern industrial society, there is no such thing as "absolutely clean air" so a goal of "zero contamination" is totally unfeasible. When assessing air quality criteria, a balance must be achieved between improving the quality of the air and the cost of doing so. Any air quality standard must be applicable to the real world.

The goals for air quality criteria should reflect the desires of the public (even if they undervalue the elimination of such effects) to eliminate the negative effects of the air contaminant (ie., health, economic damage, etc.) which should be compromised only after weighing the relative costs and benefits of different levels of air quality. It is the responsibility of air pollution control authorities to protect the public from toxic contaminants for which there may be no short term quantifiable effects.

Technological and economic constraints influence the set of conceivable air quality alternatives. The choice of an air quality standard yields a preferred technological alternative and strategies for attaining it.

When setting a standard, both ambient and emission standards may be advisable. Generally speaking, ambient standards as a goal are more acceptable than emission standards patterned after "best available technology". Such emission standards limit the flexibility of the industry in selecting a mode of control from the available alternatives. On the other hand, history indicates that the good will of industry cannot always be relied on. Therefore, both ambient air and emission standards may have a function.

09.02 ASBESTOS AIR POLLUTION STANDARDS

09.02.01 INDUSTRIAL STANDARDS

The first standard for controlling occupational exposure to asbestos dust was recommended by Dreessen et al in 1938. A limit for asbestos dust in the textile industry was set at 5 million particles per cubic foot (mppcf), determined by the impinger measuring technique(3). This standard, based on limited data, was described as tentative but the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Value (TLV)*for asbestos dust was 5 mppcf from 1946 to 1970.(3) In 1968 and 1969, ACGIH published notices of intended changes to lower the TLV to 12 fibres greater than 5 um in length per milliliter or 2 mppcf. In 1970 and 1971, they published a still lower limit of 5 fibres/ml (> 5 um).(3)(22) It must be recognized that the conversion of data from mppcf to fibres/ml in all asbestos operations can only be done with considerable risk to the validity of the results.

In 1968, the Committee on Hygienic Standards of the British Occupational Hygiene Society (BOHS) published "Hygienic Stnadards for Chrysotile Asbestos Dust" for occupational environments. It was felt that as long as there was asbestos dust in the work place, there would be a small risk to health, but that exposure up to certain limits can be tolerated for a lifetime without incurring undue risks.(21) By time-weighting exposure levels, the BOHS felt that they could reduce the risk of contracting asbestosis to 1% of those who have a lifetime's exposure to the dust.(21)

* TLV's are based on exposures of 8 hrs/day and 5 days/week.

The Occupational Safety and Health Association (OSHA) also had a previous standard of 12 fibres/ml (greater than 5 microns) and reduced this to 5 fibres/cc (> 5 um) in 1972. Under increasing pressure from the A.F.L. - C.I.O., OSHA has recently proposed a new standard of 2 fibres/cc to be implemented in 1975-76.(3)

In Ontario, a standard of 2 fibres/cc was set for asbestos in 1972 but, it is proposed by the Ministry of Health that blue (crocidolite) asbestos be limited to 1/10th of that figure. Since only one variety of blue asbestos (Cape Town crocidolite) seems to be harmful and all crocidolite in Canada is imported, the Ministry of Health has been recommending that the use of blue asbestos be stopped entirely.(22) At least one company, Ontario Hydro, has complied with this recommendation.(22)

Table 1. lists present and proposed asbestos air quality standards, relating to both industrial and ambient air.

09.02.02 AMBIENT AIR CRITERIA

A. ENVIRONMENTAL PROTECTION AGENCY (E.P.A.)

The E.P.A. ambient air standard, which was 2 years in the making (1971-73), is totally descriptive as can be seen from Appendix 09.A. It was felt that asbestos was too important to the nation's economy to be eliminated entirely (even though it was recognized as a hazardous material) so, based on the admittedly inconclusive health information presented in several E.P.A. reports,(13)(14)(15)(16)(17) a descriptive standard of no visible emissions was instituted. This can be considered only as a minimum baseline ambient air standard.

B. STATE OF CALIFORNIA

At present, there are no numerical ambient air standards for

TABLE 1.

ASBESTOS AIR POLLUTION STANDARDS

REGULATING AGENCY	ASBESTOS-CONCENTRATION STANDARD	REFERENCE
A. Industrial Standards -		
ONTARIO		
Occupational Health Branch Ministry of Health	2 fibres (> 5 um)/cc	(22)
+ Occupational Health Branch Ministry of Health	.2 fibres (> 5 um)/cc (for Blue asbestos)	(22)
UNITED STATES		
American Conference of Governmental Industrial Hygienists (ACGIH)	5 mppcf	(19)
+ American Conference of Governmental Hygienists (to be instituted in 1976)	2 fibres (> 5 um)/cc	(6)
Occupational Safety and Health Association (OSHA)	5 fibres (> 5 um)/cc	(5)
+ Occupational Safety and Health Association (to be instituted in 1976)	2 fibres (> 5 um)/cc	(5)
U.S. Department of Labour	5 fibres (> 5 um)/ml	(20)
BRITAIN		
British Occupational Hygiene Society Standards (BOHS)	0.056 mppcf-yrs. for 50 yrs. (2×10^6 particles-years/m^3) 0.112 mppcf-years for 25 yrs. (4×10^6 particle-years/m^3) 0.28 mppcf-years for 10 yrs. (10×10^6 particles-yrs/m^3)	(21)
JAPAN		
Bureau of Labour Standards	5 fibres (> 5 um)/cc	(18)
B. Ambient Air Standards		
UNITED STATES		
Environmental Protection Agency (EPA)	Descriptive Standard (See Appendix 09.A)	(17)

TABLE 1. (Cont'd)

REGULATING AGENCY	ASBESTOS-CONCENTRATION STANDARD	REFERENCE
CALIFORNIA		
+ Air and Industrial Hygiene Laboratory, California State Department of Health	Total fibre count downwind of an asbestos emission source must not exceed 10 times the total fibre count upwind of that source.	(10)
CONNECTICUT		
+ Department of Environmental Protection, State of Connecticut	30 ng/m^3 (based on 30-day average sample)	(5)
ONTARIO		
Ontario Ministry of the Environment Air Resources Branch	Interim guideline of 5 ug/m^3	

+ Indicates proposed standards.

NOTE: All industrial standards specify optical microscopy analytical procedures while all ambient air standards require electron microscopy for analyses.

the State of California. In January of 1973, Director Hodges of the State Department of Public Health wrote in a memorandum to the California Air Resources Board:(10)

> "The possibility of general increase in malignant mesothelioma and the likelihood that several decades would have to pass before we could detect this effect makes it incumbent upon us to restrict unnecessary asbestos exposure as much as possible. It is to that end that is is proposed that air quality standards be set. The possible role of community asbestos in cancer of the lung gives added importance to this proposal."

He further stated:

> "It is appropriate and reasonable to require upwind and downwind monitoring by any user whose activities are likely to lead to appreciable (4x to 10x) increases in community asbestos exposure... It would be appropriate and reasonable for the State Department of Public Health with assistance of an advisory group to review the health implications of asbestos exposure and to make further recommendations for air quality standards and for control."

This proposed standard, which avoids an actual ambient air figure, is considered a somewhat temporary regulatory step until new, more conclusive proof can clear up the areas of controversy.(9)(10)(11)(12) Dr. J. Wesolowski, Director of the Air and Industrial Hygiene Laboratories (A.I.H.L.), California State Department of Health, has recently been conducting intensive experimentation in conjunction with the E.P.A. and Mt. Sinai Institute involving the measuring of asbestos concentrations.(12) State authorities are beginning to define their roles and functions regarding asbestos for action in the near future.(12)

C. STATE OF CONNECTICUT

The Department of Environmental Protection, Air Compliance Unit of the State of Connecticut has recently proposed an asbestos ambient air quality standard of 30 ng/m^3 based on a 30 day sampling period. The criterion of mesothelioma was selected as the rationale for developing this proposed standard. An asbestos concentration versus mesothelioma incidence envelope for the general population, based on mesothelioma incidence due to industrial exposure, was utilized in developing the proposed asbestos standard of 30 ng/m^3. This standard, in the opinion of the Connecticut authority, is projected to reduced nationwide asbestos-related fatalities feasible since available ambient air asbestos data indicates that non-urban and remote non-urban areas have asbestos levels typically less than 1 ng/m^3 while urban areas are usually below 30 ng/m^3. The Air Compliance Unit and Mr. L. Bruckman released several reports in 1973 and 1974 establishing their position.(5)(6)(7)

In a recent communication with Mr. Bruckman, senior air pollution control engineer of the Air Compliance Unit, it was learned that the State is currently conducting a sampling program to establish the general asbestos environment in Connecticut.(8) Policy decisions will be made when the results of the sampling survey are available.(8)

D. ENVIRONMENT CANADA

The Mining, Mineral and Metallurgical Division of Environment Canada based in Ottawa, is also considering limiting asbestos emissions into ambient air for Canada. At present, they are assembling data based on responses from questionnaires, conducting an environmental sampling program, and preparing a draft report on the mineral. Although not ready to promulgate a specific figure as of yet, a recent communication confirmed that any standard would be based on best practical technology.(23)

09.03 AIR QUALITY CRITERIA

One goal for the choice of any air quality criteria is the minimization of the risk of asbestos-induced health effects incurred by the general population. Inconclusive information on these effects make the initiation of a responsible asbestos standard difficult. In analyzing accurately the effect of community exposure, the association between low levels of asbestos dust and cancer and mesothelioma must be clearly understood but, as NIOSH reports: "for carcinogenic agents, a safe level for man cannot be established by application of our present knowledge".(3) Some effects are detectable in occupations where overall exposures are minimal and with indirectly exposed populations but, it seems likely that these exposure levels are greatly in excess of those asbestos concentrations generally found in the ambient air of urban communities. For these reasons, it is recommended that present average urban ambient levels not be allowed to increase (beyond a factor of 2 or 3), thereby limiting instances of asbestos-induced cancer and mesothelioma to a strict minimum among the general population until further information is available.

The purpose of a stringent air quality standard would be to force the use of "best available technology" to control conventional sources of asbestos emissions into the atmosphere. As has been previously reported, the sources of asbestos emissions are so varied that the customary control alternatives will not be sufficient to regulate all ambient air emissions (ie., asbestos mining operations, outside disposal of asbestos, service centers that deal with automotive brake linings, etc.). A code of practice for such operations would be required, again based on the best practical technology available.

It is felt that there should be no trouble in maintaining current asbestos background concentrations using "best available technology" techniques. This is also the view of Bruckman in Connecticut who considers their standard, equivalent to average background levels, easily met by fabric filter control techniques.(5)

If it is assumed that the slope of the averaging time versus maximum concentration graph for asbestos is the same as suspended particulate matter then, from the measured 5-8 hour samples, the frequency distribution line for asbestos can be drawn parallel to the total suspended particulate (since it is a component of S.P.M.) and extrapolated to 30 minutes.

A more specific way of determining a 30 minute design standard is by accurately calculating a fibre concentration frequency distribution uniquely for asbestos. Asbestos filter samples, based on 4-8 hour time intervals, can yield a particle size distribution as well as a frequency distribution of the concentration of fibres to be expected in urban air. It is suggested that data collected near point sources be kept separate from ambient air background data and two separate frequency distributions be plotted. It would be expected that the log normal distribution from the point sources would have a much steeper slope (higher standard deviation) than the ambient air data. Using the frequency distribution obtained from background studies and deciding on an allowable geometric mean, the ambient air criteria can be estimated with some assumptions.

Based on long-term ambient air measurements, a more accurate determination of air quality criteria showing the maximum concentration allowable over a period of time can be derived by plotting the maximum readings (fibre concentration) versus averaging time on log/log paper. In this way, samples taken over 4-8 hour intervals can be directly related to 30 minute maximum values as well as yearly values.

It may prove possible to use the fibre size distribution to obtain fibre concentration frequency distributions for fibres in discrete size ranges but, this will require the experimental data before the feasibility can be determined.

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10. PROGRAM DESIGN AND COST

An initial ambient air asbestos sampling program designed to appraise the situation in Ontario is required before any responsible air quality criteria can be formulated. The program will focus on fulfilling these two major goals:

(1) to acquire an indication of present asbestos concentrations in ambient air in Ontario;

(2) to acquire knowledge of the character (ie. - size distributions, etc.) of the sampled asbestos from various sources/sites.

10.01 ASBESTOS AMBIENT AIR MONITORING SURVEY

10.01.01 OBJECTIVES

The asbestos sampling survey is to:

(1) determine ambient asbestos levels removed from large sources in various representative Ontario urban, suburban, rural and remote areas;

(2) determine asbestos levels in the vicinity of industrial users and producers. Specifically:

  (a) to determine a range of asbestos concentrations to be expected from various asbestos operations;

  (b) to determine the "region of influence" of industrial sources with regard to the area over which it has an effect, the number of people exposed and the degree of exposure.

(3) determine the character of airborne asbestos, particularly size distribution, from selected sources in order to provide information for:

(a) toxicity evaluation by medical advisors;

(b) a length limit from which a fairly accurate size distribution could be estimated, which would facilitate easier and less expensive monitoring to be included as part of the standard.

(4) to assess what levels of asbestos might be achievable with present technology;

(5) to provide some data on airborne asbestos in the vicinity of the mines;

(6) to encourage abatement measures and aid in the setting of abatement priorities;

(7) to compare nuclepore and delbag sampling methods to develop a future monitoring technique;

(8) to aid in the development of a criteria.

It should be noted that, with present funding, all of these objectives may not be achievable. However, the design of the program should take them into account as far as possible. Because of the cost of analyzing a filter for asbestos, it is suggested that more filters be collected than are analyzed.

The period of time in which the sampling program will be executed will cover 7 months with the completion date scheduled to be July, 1975. Sampling will be conducted in winter as well as summer months. A meteorologist should be consulted when determining which sample filters should be analyzed.

10.01.02 SURVEY STRATEGY AND DESIGN

The recommended sampling program has been broken down into five categories with individual processes/sites as sub-categories. Criterion for category choice is homogeneity of source type rather than process or industry groupings. This provides easy comparability (and therefore selectivity) of sites within the category which will use approximately the same sampling strategies (regardless of product manufactured). When choosing manufacturing establishments to sample within categories, amounts of asbestos used, control techniques employed and all other variables involved (ie., land-use, dispersion, etc.) must be determined so as to try and assess the environmental hazard. Plants with the highest expected emission rates would be considered for sampling. Table 1. lists these categories more completely, presenting the sampling strategy for each site and the number of sites that can be monitored within each category under the present budget. The sites to be sampled have been identified and placed within each of the Regions of the Ministry of the Environment.

It is very important that ambient concentrations be determined throughout Ontario since they will be very instrumental in control monitoring. Once these concentrations are determined, they will serve as a reference, and expansion of the present or any future programs need not concentrate on ambient levels. In Ontario, large asbestos manufacturers (using more than 1,000 tons per year of asbestos) amount to five. Three, or 60% of the firms were choosen for sampling; an asbestos-cement manufacturer, a gasket and automotive parts manufacturer, and a vinyl-asbestos tile manufacturer. Asbestos manufacturing in Ontario consists generally of small operations, many with little or no control equipment, bad land-use and little or no stack venting. These small establishments could pose an environmental problem (especially where there are numerous plants of this nature in the same area) and warrant extensive (as possible) monitoring. Eleven sites have been chosen, but this amounts to approximately only 9% of all the small asbestos operations in Ontario. However, the plants chosen to be monitored in all Regions cover a broad spectrum of

TABLE 1. SAMPLING STRATEGY

CATEGORY/PROCESS	NUMBER OF SAMPLES PER SITE	NUMBER OF SITES TO BE SAMPLED (APPROX.)	CRITERIA FOR CHOICE
(1) Mining and Milling	Monitoring of the Milling Operation only: 1 Sample upwind 3 Samples downwind 4 Samples Total: 4 samples/site.	Hedman Mill: Site monitored once in winter and once in the summer. Reeves Mill: Site monitored once in the summer.	Although the mining and milling process is recognized as a large emitter of asbestos and, therefore, a large potential hazard, it is felt that the number of people affected by Ontario mines is very low so attention will be centered on the milling operation where the asbestos ore is processed into fibre.
(2) Large Manufacturing includes: Asbestos Cement Asbestos Textiles Friction Products Asbestos Paper	1 Sample upwind 6 Samples downwind 7 Samples total Each site is sampled twice once in winter, once in summer. Total: 14 samples/site.	3 Plants	Large plants require more sampling than small for assessment. "Large" is determined by asbestos used. Elevated sampling techniques are involved. Plants to be monitored should be chosen after assessment of all variables involved.
(3) Small Manufacturing (Uncontrolled) Includes: Asbestos Cement Asbestos Textiles Friction Products Asbestos Paper Asbestos Tile	1 Sample upwind 3 Samples downwind 4 Samples total Each site sampled twice: once in winter, once in summer. Total: 8 samples/site.	11 Plants	Small manufacturing operations emit small quantities of asbestos unless uncontrolled. Less samples are needed to evaluate each source. Companies in recent trouble with the Ministry of Health and/or the Ministry of the Environment should be seriously considered for monitoring.
(4) Ambient (typical) - Urban - Suburban - Rural - Remote	6 Samples per site taken once a month for 6 months	11 Sites	Urban ambient concentrations in several Ontario cities monitored. Suburban locations will have to be in a large city, probably in Southern Ontario. Rural sites chosen must be very representative and neutral. The remote sites are to estimate the backgrounds in Ontario.
(5) Special Considerations: - TTC Subway - Construction - Demolition	TTC: 2 samples per site. Construction 1 Upwind Demolition 3 Downwind 4 Total Urban transit routes: 4 samples per site taken once every two months	8 Sites	Construction/Demolition may present the greatest overall hazard along with mining and milling. It will be treated the same as small manufacturing.

asbestos products. Asbestos textile, asphalt, cement, and packing firms are represented as well as asbestos insulated wire, reinforced plastic and asbestos brake lining and relining establishments in addition to asbestos construction materials. All plants, after being inspected, are expected to have a potential emission hazard. Following, is the sampling strategy for each Region.

Northwestern Region:

Only the typical ambient levels of asbestos will be monitored in the city of Thunder Bay.

Northeastern Region:

The two operating and one proposed mine and mill operations are located in this region. The Reeves and Hedman mills will be monitored as per description of Table 1. The proposed United Asbestos mining/milling operation will serve the dual purpose of providing a "remote site" location as described in Category 4, Table 1, and serve as a reference for control monitoring when the mine begins production in 1975. It is proposed that three samples be taken at the employee camp site located about 1 mile from the operation and three samples in a southwesterly direction from the future location of the mill. Background monitoring of the city of Timmins is recommended.

Southeastern Region:

Only the typical ambient levels of asbestos in Ottawa will be monitored in this region.

West Central Region:

In addition to the general ambient asbestos concentrations in Hamilton, this region feels that the following company warrants monitoring (as described in Category 3, Table 1.):

Plastic and Asbestos Products Ltd.,
618 Parkdale North, Hamilton, Ontario.

As described in Category 5, Table 1, at least one multi-story construction site should be chosen in Hamilton as well as two urban transit sites.

Southwestern Region:

Three typical ambient sites are recommended in this region; one in London where potential asbestos emitters are small, but numerous and generally poorly controlled; one in Windsor, and one rural sample located in Perth County to determine background levels for Southern Ontario. Also in this region are two manufacturers using a small quantity of asbestos but potential emissions are expected. They are:

(1) Dow Chemical Ltd.,
Sarnia, Ontario.

(2) Raymond Brothers Ltd.,
182 York Street, London, Ontario.

They should be monitored as described in Category 3 of Table 1.

Central Region:

In this region, typical urban asbestos levels will be determined in Peterborough and Toronto (one downtown site and suburban site, either in Rexdale or the Bayview/Eglinton area). As described in Category 5 of Table 1., special consideration will be given to the TTC subway system where 2 sites will be chosen, construction sites where one location will be chosen and urban transit routes where two sites will be monitored (areas where brakes are regularly applied are of prime concern). As described in Category 2, Table 1., there are 3 large manufacturing operations that require monitoring. They are:

(1) Canadian Johns-Manville Co. Ltd.,
5421 Lawrence Ave. E., Toronto.

(2) Raybestos-Manhatten (Canada) Ltd.,
1944 Crawford Drive, Peterborough, Ontario.

(3) Flintkote Co. Canada,
30th Street, New Toronto.

In addition to these companies, there are several smaller manufacturing operations which, as described in Category 3, Table 1, require monitoring. They are as follows:

(1) Canadian Wire and Cable,
147 Laird Drive, Toronto.

(2) Chevron Asphalt Ltd.,
43 Industrial, Toronto.

(3) Consolidated Sand and Gravel,
37 Commercial Road, Toronto.

(4) Texas Refinery Corp. of Canada,
25 Industrial, Toronto.

(5) Protective Plastics Ltd.,
84 Railside Drive, Toronto.

(6) Scandura-Mintex Canada Ltd.,
Rexdale, Ontario.

(7) Brake Bonding,
Etobicoke, Ontario.

(8) Garlock of Canada,
66 Tutland Road, Toronto.

(9) Abex Industries Ltd.,
50 Colborne St. W., Lindsay, Ontario.

10.01.03 SURVEY COST

The Ontario Research Foundation and the Department of Geology at McMaster University are the two Ontario institutions that analyze asbestos on ambient air filters. The cost estimates are based on $160 per sample filter analyzed. Copies of ORF's and McMaster's proposals for analysis of filters provided by the sampling program out-

For the money, the Air Resources Branch of the Ministry of the Environment requires a four page per sample computer printout with the actual raw data and:

- the number of fibres per cubic centimetre
- an estimate of the mass
- size categories (a) length breakdown
  (b) width breakdown
- particle size distribution
- cumulative size distribution
- cumulative mass distribution
- amphibole/chrysotile data breakdown.

Dr. E.J. Chatfield, head of ORF's electro-optical laboratory studies the asbestos samples with a transmission electron microscope and electron diffraction techniques (no extra charge). The precision of the method is within .01 fibres/cc. (with every 5 m^3 of air sampled). Chatfield states that he can not identify the amphibole series, but chrysotile can be positively identified. Recent experience strongly suggests that experience in counting asbestos is an important factor in determining the accuracy of the analysis.

Approximately \$3,500 to \$4,500 will be required by the Technology Development and Appraisal Group of the Ministry of the Environment for new equipment (ie., pumps, flow meters, filter heads, filters, etc.).

A Regional cost summary for analysis of asbestos filters is presented in Table 2. The total cost for the survey will be \$39,100 or 236 samples analyzed. With additional money in the new fiscal year, expansion of the program could develop with special attention paid to large and small asbestos manufacturers in Toronto and small automotive brake relining establishments in London, Ontario.

Parallel sampling using delbag and nuclepore techniques will be conducted for comparative purposes in conjunction with the Central Region of the Ministry of the Environment. To be statistically valid, a minimum of twenty delbag samples will be required. Since the cost of analysis is the same as for nuclepore, the total expenditure will be $3,200 to be incurred by the Technology Development and Appraisal Section. This, then, specifies the Section's expenditure to be $42,300.

TABLE 2.

REGIONAL COST SUMMARY

Northwest Region:

1 Urban Background Site
- 6 sample filters

Total Cost - $960

Northeast Region:

2 Milling Operations
- 12 sample filters

1 Urban Background Site
- 6 sample filters

1 Remote Background Site
- 6 sample filters

Total Cost - $3,840

Southeastern Region:

1 Urban Background Site
- 6 sample filters

Total Cost - $960

Central Region:

3 Large Asbestos Manufacturing Sites
- 42 sample filters

9 Small Asbestos Manufacturing Sites
- 72 sample filters

3 Urban Background Sites
- 18 sample filters

5 Sites of Special Consideration
- 4 sample filters at 2 TTC sites
- 4 sample filters at 1 construction site
- 8 sample filters at 2 urban transit sites

Total Cost: $23,680

Cont'd........

West Central Region:

1 Small Asbestos Manufacturing Site
- 8 sample filters

1 Urban Background Site
- 6 sample filters

3 Sites of Special Consideration
- 4 sample filters at 1 construction site
- 8 sample filters at 2 urban transit sites

Total Cost - $4,220

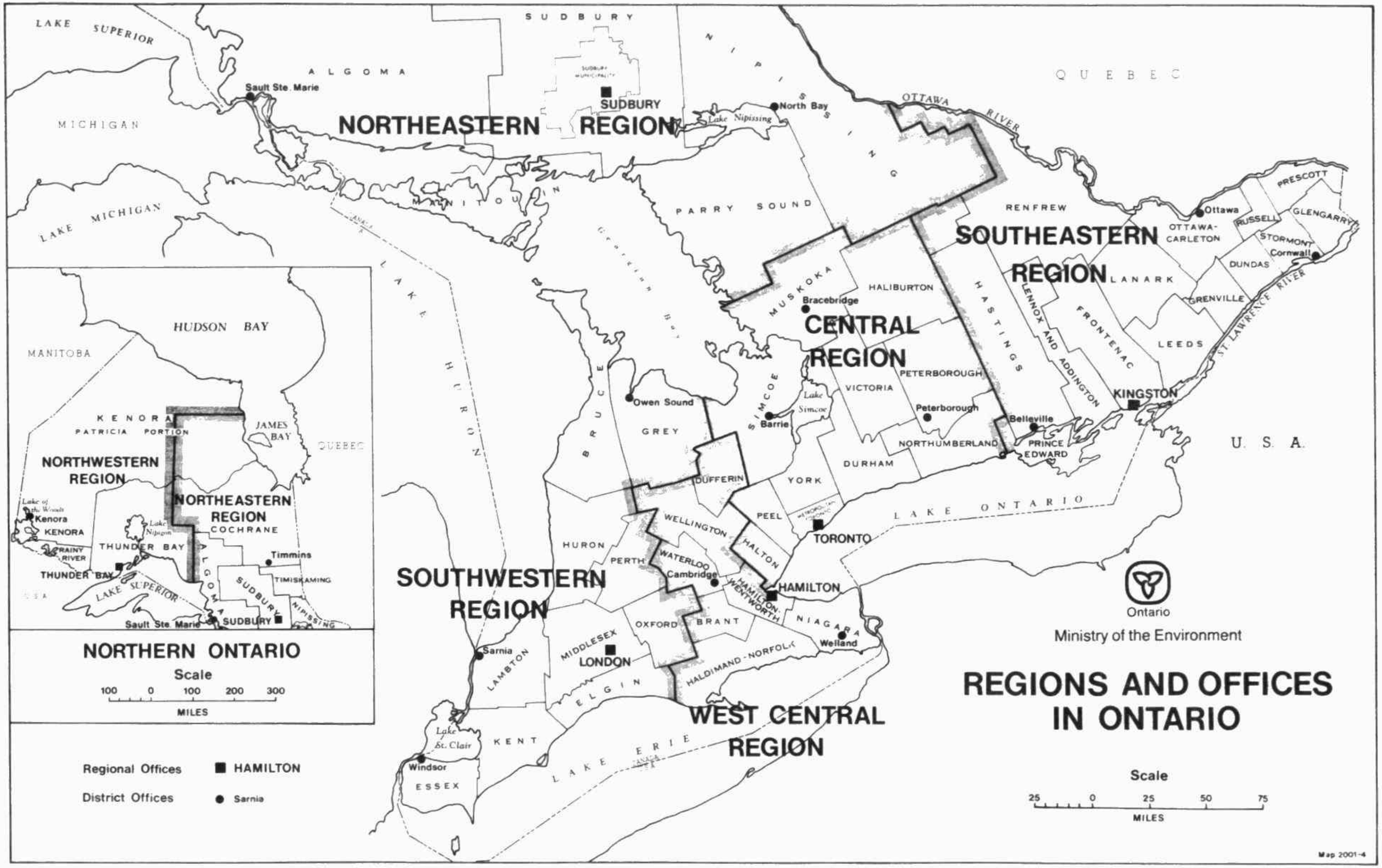
Southwestern Region:

2 Small Asbestos Manufacturing Sites
- 16 sample filters

2 Urban Background Sites
- 12 sample filters

1 Rural Background Site
- 6 sample filters

Total Cost - $5,440


REGIONS AND OFFICES IN ONTARIO
Ontario
Ministry of the Environment
NORTHEASTERN REGION
SOUTHEASTERN REGION
CENTRAL REGION
SOUTHWESTERN REGION
WEST CENTRAL REGION
NORTHWESTERN REGION
NORTHERN ONTARIO
Scale
100 0 100 200 300
MILES
Regional Offices
HAMILTON
District Offices
Sarnia
Scale
25 0 25 50 75
MILES
Map 2001-4
LAKE SUPERIOR
MICHIGAN
LAKE MICHIGAN
LAKE HURON
Georgian Bay
LAKE ONTARIO
LAKE ERIE
Lake St. Clair
Lake Simcoe
Lake Nipissing
OTTAWA RIVER
ST. LAWRENCE RIVER
QUEBEC
U. S. A.
HUDSON BAY
JAMES BAY
MANITOBA
SUDBURY
ALGOMA
NIPISSING
MANITOULIN
PARRY SOUND
MUSKOKA
HALIBURTON
RENFREW
HASTINGS
LENNOX AND ADDINGTON
FRONTENAC
LANARK
OTTAWA-CARLETON
PRESCOTT
RUSSELL
GLENGARRY
STORMONT
DUNDAS
GRENVILLE
LEEDS
PRINCE EDWARD
NORTHUMBERLAND
PETERBOROUGH
VICTORIA
DURHAM
YORK
SIMCOE
PEEL
HALTON
HAMILTON-WENTWORTH
NIAGARA
HALDIMAND-NORFOLK
BRANT
OXFORD
WATERLOO
WELLINGTON
DUFFERIN
GREY
BRUCE
HURON
PERTH
MIDDLESEX
LAMBTON
ELGIN
KENT
ESSEX
KENORA
PATRICIA PORTION
RAINY RIVER
THUNDER BAY
COCHRANE
TIMISKAMING
Sault Ste. Marie
SUDBURY
North Bay
Ottawa
Cornwall
KINGSTON
Belleville
Peterborough
Bracebridge
Barrie
Owen Sound
TORONTO
HAMILTON
Cambridge
Welland
LONDON
Sarnia
Windsor
Kenora
Timmins
Lake of the Woods
Lake Nipigon

10.02 SOURCE TESTING

If the results of the asbestos ambient air monitoring survey indicate that there is a significantly hazardous situation in Ontario, source testing will be warranted and a stack sampling program will begin.

10.02.01 OBJECTIVES

The objectives of a source testing program are:

(1) to aid in the development of a point of impingement, 30-minute design standard;

(2) to determine the fibre size distribution to be expected from different manufacturing processes;

(3) to obtain information for the assessment of control equipment and its efficiency;

(4) to obtain an indication of the asbestos concentrations to be expected from various sources;

(5) to obtain information which can be used to estimate a conversion factor from mass concentration to a fibre per cubic meter (f/m^3) basis useful in the formulation of a 30-minute design standard.

10.02.02 PROGRAM DESIGN

The decision to implement this program will be made after the results of the ambient air monitoring program are obtained and assessed.

Prior to the initial source testing surveys, research must be conducted by the Technology Development & Appraisal Group into acceptable sampling equipment and techniques. Three or four different techniques will be tested on one convenient source with approximately 12 samples involved. After optimization of sampling technique is derived, the survey can be initiated.

The source survey will consist of source/stack testing and inlet/outlet determinations of efficiency. This sampling can be conducted concurrently on each plant. Five manufacturers will be surveyed requiring about 6 samples each. At the moment, the companies are not chosen, but criteria for the choice will include diversity of processes, control equipment, as well as suspected problem plants. The choices will be made from the Central Region and will probably follow the lead of the ambient air sampling survey choices. In addition to these industrial sites, source testing of the two producing chrysotile mines in the Northeastern Region will be conducted. The mine/mill operations will require 6 samples each.

10.02.03 SURVEY COST

It has been recommended that the source testing survey be contracted to a consulting firm outside the Ministry of the Environment to be offered and evaluated by the Technology Development and Appraisal Group. The cost is estimated at $1,100 per sample with the following breakdown:

- $800 for the equipment and services of the consultants;
- $160 for analysis of sample filters;
- $140 for miscellaneous expenses.

TABLE 3.

SOURCE TESTING SURVEY COST*

PURPOSE	SAMPLING STRATEGY	NUMBER OF SAMPLES REQUIRED	TOTAL COST
Research	4 techniques to be tried @ 3 test samples each.	12	$13,200
Stack sampling of manufacturing operations	5 sources to be monitored @ 6 test samples each.	30	$33,000
Source testing of mining and milling operations	2 mine/mill operations to be tested @ 6 samples each.	12	$13,200
	TOTAL	54	$59,000

* This does not include scaffold, fabrication, and travel costs.

ADDENDUM TO "ASBESTOS AS A HAZARDOUS CONTAMINANT",
REPORT NO. ARB-TDA-01-75, AIR RESOURCES BRANCH,
ONTARIO MINISTRY OF THE ENVIRONMENT, 1975

SECTION 08. HEALTH EFFECTS, pages 185A - 185D
(Prepared by Ontario Ministry of Health, May, 1976)

Health Aspects

Studies of the biologic response to different types of asbestos dusts indicate that their inhalation in adequate concentration can produce pulmonary and pleural fibrosis (scarring) and/or several types of malignancies. The biological response depends on the length of the inhaled fibre. Fibres longer than 20 microns are easily intercepted in the upper airways whereas fibres shorter than 5 microns may reach the terminal airways and the alveoli where gas exchange takes place. At present it is thought that it is the fibres between 5 and 15 microns long that create the health problem of asbestosis.

The smaller particles or fibres, when engulfed by a scavenger cell (Macrophage), are coated by these cells with protein-like material. Such coated fibres are found both in the alveoli and in the lung tissue and are called "asbestos bodies". They may be expectorated and can be identified in the sputum. Fibres can also penetrate the lung tissue and finally reach the fine membrane (pleura) covering the surface of the lungs and the inner side of the chest wall. The response of the pleura can be: pleural effusion or thickening and scarring of the pleura or malignancy (mesothelioma). At present there is no evidence that mesothelioma must develop from pleural thickening.

Neither asbestos bodies nor pleural changes are signs of the disabling disease "asbestosis". They just prove, that the afflicted person has been exposed to asbestos inhalation.

Asbestosis

The inhaled asbestos fibres which were not removed by the biological process of lung clearance and were not coated with proteinaceous material irritate the lung tissue and cause fibrotic changes or scarring. This scarring increases the thickness of the alveolar wall and interferes thus with the air-exchange and makes the lung shrink so that the lung can take up only a restricted volume of air, in comparison with healthy lungs. Asbestosis is a restrictive lung disease. The scarring of the lung is opaque for X-rays and can be visualized on a chest X-ray film.

The time necessary from the start of exposure to the development of asbestosis is on the average 20 years, but it varies with the dust concentration in the inhaled air. It is shorter, when the concentration is larger and longer when the concentration is smaller.

Cancer of the lungs in persons with asbestos-induced fibrosis

Both epidemiological studies of people exposed to asbestos and of experimental animals give results showing that when the exposure to asbestos is large enough to induce fibrosis of the lungs, lung cancer may develop. Any type of fibre can cause lung cancer although there is evidence that amphibole fibres (Crocidolite, Amosite and others) are of somewhat greater carcinogenicity. Cigarette smoking seems to be synergistic with asbestos fibres in causing cancer of the lungs. In the Province of Ontario all workmen compensated for asbestos induced lung cancer have been smokers.

Mesothelioma

Mesothelioma is a very rare cancer arising from the covering membranes of the lungs and of the abdominal cavity. In Canada the annual deaths from this tumor are about one per million people. Its connection with asbestos was suspected for the first time in South Africa, where by 1962 one hundred and twenty-one (121 cases) had been discovered, 110 of whom occurred in persons who either worked in asbestos mines or lived in the neighbourhood of an asbestos mine. Contrary to the lung cancer in asbestos cases, mesothelioma does not show a dose-effect relationship. That means that asbestos exposure could have been a very short and small one, not sufficient to induce asbestosis of the lungs. As with carcinoma, mesothelioma can be induced by any asbestos group, but its prevalence is much higher among people who were exposed to fibres of the amphibole group.

There is no specific treatment of asbestosis and the only way to fight this disease is by prevention. Prevention must be both by technical means and by medical surveillance, particularly of exposed workers.

Medical surveillance includes a preplacement examination complemented by a chest X-ray examination and with pulmonary function tests. It is not advisable, that people with chronic lung disease interfering with lung clearance,such as chronic bronchitis,or with asthma,should be allowed to work in asbestos exposure. People whose vital capacity (amount of air taken in with a maximal deep breath) is less than 80% of the predicted value should not be employed in exposure to asbestos dust. Ideally, smokers should not work where there is an occupational exposure to asbestos.

Workers employed in asbestos hazard should be examined annually, and, after 20 years of exposure, semi-annually, and these examinations must include chest X-rays and pulmonary function tests. Employees with proven pleural reactions combined with asbestos fibres in the sputum or a decline of vital capacity should be advised to discontinue work in asbestos exposure.

Environmental Aspect

Because of the very wide use of asbestos in both construction and in consumer products, fibres can be found almost everywhere - in the ambient air, in drinking water, even in some foods. This ubiquity of fibres makes it very difficult to determine whether they have any effect on health, and if so, what concentration of fibres is required to produce such effects.

As has been mentioned above, a disproportionately large number of cases of mesothelioma have occurred in people who had been exposed only by living near a source of asbestos. These are the only cases in which an environmental asbestos exposure can be fairly reliably related to an identifiable disease.

There is still a great deal that is unknown about this whole subject. If, as has been postulated, a very brief exposure can result in mesothelioma, and, given the widespread occurrence of asbestos fibres, one could well ask why mesothelioma is not much more common than it is. The most pessimistic view that has been expressed is that the most widespread use of asbestos is of relatively recent origin (about 30 years) and that the number of cases may greatly increase in the future. On the other hand, most of the cases of mesothelioma referred to above were associated with amphiboles (crocidolite or amosite) and it may be that the more common chrysotile has little or less effect.

Although there has been a great deal written about asbestos, it is apparent that there is still a great deal to be learned about the extent to which it can affect human health.

Ministry of Health
May 1976.